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EXPERIMENTAL RESEARCHES ON THE SKIN EFFECT IN STEEL RAILS.*

BY

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THE following research was conducted during the years 1914–15–16, at the Massachusetts Institute of Technology, under an appropriation from the American Telephone and Telegraph Company. In the earlier part of 1914, it was conducted under the directorship of Prof. Harold Pender. The research originated in a thesis at the Massachusetts Institute of Technology in 1913–14, by Mr. R. W. Weeks, in the Department of Electrical Engineering.

Objects of the Research.—The research was made to determine, by direct measurement, the impedance offered, to alternating currents of the strengths likely to be employed in electric-railway work, by standard steel rails of various shapes and sizes; also, to ascertain how this impedance varied with frequency and with current-strength, and whether the impedance could be reduced to a simple engineering theory, so as to admit of being predicted, within reasonable limits, from physical data concerning the steel used in the rails. It is believed that some progress is here presented in each of these directions.

Types and Dimensions of Rails Tested.—The tests were extended to 11 sample track rails and 2 sample contact rails, 33 feet

* Communicated by Dr. Kennelly, April 14, 1916.

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(10.07 metres) in length, ranging in linear mass from 60 to 100 pounds avoirdupois per yard (30 to 50 kilogrammes per metre), with corresponding cross-sections from 6 to 10 square inches (38.5 to 64.5 square centimetres). The cross-sections of these rails are represented to scale in Figs. 5 to 10.

Frequencies and Strengths of Alternating Testing Current.—Three frequencies have been used in the tests; namely, 25, 45, and 60 cycles per second. The bulk of the work was, however, carried on at or near two frequencies only; *i.e.*, 25 and 60 cycles per second.

The current-strengths employed in the test rails varied from 10 to 800-ampères r. m. s.

FIG. 1.

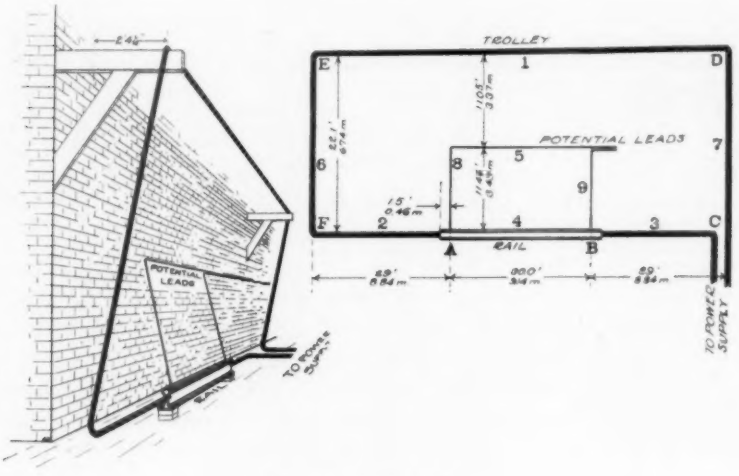


Diagram of test circuit.

Arrangement of Test Circuit.—In order to make the measurements as nearly under practical railway conditions as possible, the test circuit was so constructed that the rail and its parallel return conductor occupied the same relative positions as one rail of a railroad track and its overhead trolley wire (No. 0000 A. W. G., diameter 0.46 inch, or 1.17 centimetre); *i.e.*, with the trolley wire 2 feet 4½ inches (71.8 centimetres) to one side of the rail and 22½ feet (6.86 metres) above it. The arrangement of the test circuit is shown in Fig. 1. *AB* is the rail under test, occupying a horizontal position raised about 1 foot (30 centimetres) above

the ground on brick pillars. The rest of the rectangular loop *BCDEFA* was composed of straight copper conductors (wire or cable). The extensions *AF* and *BC* from the ends of the rail were made so as to enable the electro-magnetic field in the neighborhood to be both more nearly uniform and more readily calculated. The circuit was erected in an alley between two brick buildings, remote from iron. A photograph of the rail in position appears in Fig. 2.

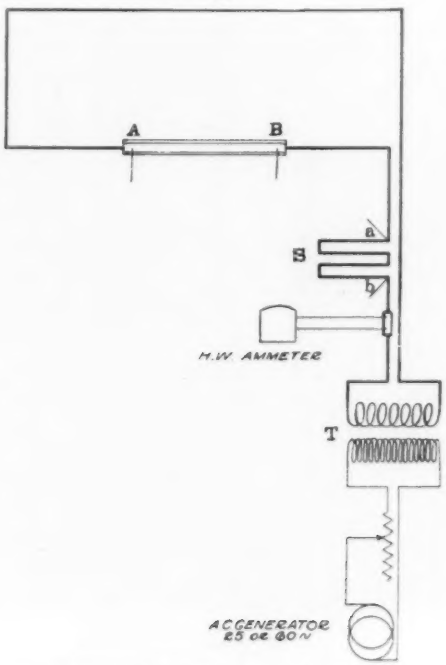
FIG. 2.

Rail in position for test.

Sources of Alternating-current Supply.—For the frequency of 25 ∞, a General Electric 3-phase 50-kva. alternator, 6-pole 514 r. p. m.—230 volts—126 ampères was used. For the frequency of 60 ∞, a Mordey single-phase, 40-kva. alternator was used, with 9 poles and 9 pancake coils, for supplying about 135 ampères r. m. s., at about 300 volts. The arrangement of circuits used is shown in Fig. 3. The transformer *T* was a General Electric Company's 15-kva., 60 ∞, single-phase transformer from 220 to 18 volts. The secondary terminals were connected directly to the test circuit through two four-terminal manganin resistors, and the

primary terminals to the generator through an adjustable rheostat having very little inductance. At the frequency of 25 ∞, and maximum rail current, the primary voltage impressed on the transformer was about 230 volts, with 130 ampères or 29.9 kva. with 12.5 kw. At the frequency of 60 ∞, the corresponding primary voltage on the transformer was about 330 volts, with 125 ampères. Occasionally, tests were also made at 60 ∞, with currents from

FIG. 3.



General testing connections from generator.

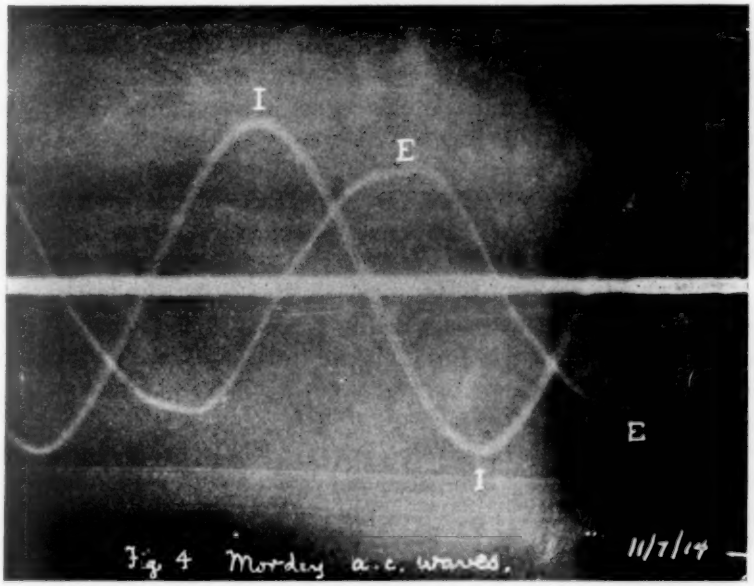
the shop mains, supplied by a General Electric Company's 14-pole, 100-kva., three-phase alternator.

The wave-form of voltage and current supplied from the Mordey generator was nearly sinusoidal, as was shown by numerous oscillograms (see Fig. 4). The wave-form of 25 ∞ voltage, from the 50-kva. generator, showed appreciable harmonics; while the wave-form of its current showed only a moderate triple-frequency harmonic. The wave-form of 60 ∞ voltage and current from the shop mains had yet more marked harmonics.

Method of Measurement.—Since no exact theory of skin effect in steel rails has yet been worked out, it was very desirable to apply more than one method of measurement, in order to secure a satisfactory experimental check upon the results. Much time had to be expended in finding two different methods of testing which would give concordant results, with steel rails, to the requisite degree of precision.

The following were the four methods tried:

FIG. 4.



Mordey a.c. waves.

Method 1.—By *astatic electrodynamometer* of fixed and moving coils, measurements were made of rail r. m. s. voltage and of rail r. m. s. current, as well as the active power expended in the rail. By an astatic dynamometer is meant one whose moving system comprises two oppositely wound coils, so arranged as to be substantially unaffected by local stray magnetic fields, either alternating or continuous. Denoting the fixed coils by F and the moving coils by M, the voltage across the rail potential points was measured with F and M in parallel, M having a suitable non-inductive resistance in its branch. The circuit current was meas-

ured by observing the voltage across the manganin strip potential points in a similar manner. The active power in the rail was measured by connecting F to the manganin strip, and M to the rail potential points, through a suitable non-inductive resistance. The dynamometer was calibrated by known continuous current passing through both coils. This method was found to be unsatisfactory. Not only does the impedance of both F and M vary to the harmonics in the traversing currents, but the mutual inductance between F and M also comes into consideration, and this varies with the deflection and angular position of M with respect to F.

Method 2.—Oscillographic measurements were made of both the voltage between rail potential points—hereafter called the "rail voltage"—and the current in the rail circuit. Fig. 4 shows one of the oscillograms obtained with 160 ampères in the rail circuit at 60 $\sim$ and about 0.72 volt across the rail, the current lagging about 71 degrees behind the voltage. The current wave is seen to be nearly sinusoidal; while the voltage wave shows faintly the presence of harmonics. From these two curves it is theoretically possible to compute the impedance of the rail, and, therefore, its skin effect, when its resistance to continuous currents is known. This method, although useful and convenient as a check, was found to be unsatisfactory in detail, owing to lack of precision in the oscillograms, and also to variations in the constants of the oscillographic vibrators.

Method 3.—The Drysdale-Tinsley alternating-current potentiometer * was used at the frequency of 60 $\sim$, measuring alternately the vector voltage across the rail and the manganin shunt. The ratio of these two measurements gives the vector impedance of the rail between potential points. This method has the advantage that, since the vibration-galvanometer of the detector circuit is tuned to the fundamental frequency, the harmonics in either voltage or current are virtually excluded, and also that the two measured values, $E \angle \alpha$ volts and $I \angle \beta$ ampères, give as their quotient $Z \angle \gamma = \frac{E}{I} \angle \alpha - \beta$ ohms. This reduces the computation of the results to a minimum. Referring to Fig. 3, the alternating-current vector potential difference was measured between points A and B on the rail, and then between points ab on the manganin strip.

A disadvantage of the alternating-current potentiometer

* Bibliography No. 17.

method is its sensitiveness to slight changes of frequency, in the vibration galvanometer and in the phase-splitting device. Under shop conditions of generator driving, it is often hard to keep the frequency constant within satisfactory limits.

Method 4.—The Sumpner dynamometer * was used to measure the current I ampères in the rail, and also to measure both active and reactive components of the rail voltage, which may be called E_R and E_x volts respectively. Then the effective resistance of the rail is $R' = E_R/I$ ohms, while the effective inductance is $L' = E_x/(\omega I)$ henrys. An outline of the theory of the use of this instrument is given in Appendix I.

In all four of the above methods, the p. d. on the tested rail was taken from two potential taps near the ends, and 30 feet (914 cm.) apart. Only two methods, viz., numbers 3 and 4, were found to give uniformly consistent results to the desired degree of precision. Tests made of the impedance of a rail by these two methods—*i.e.*, by Drysdale potentiometer and by Sumpner dynamometer—were found not to differ by more than 3 per cent. within the entire range, including discrepancies attributable to temperature variations, and they usually agreed within 1 per cent. Check tests were also made by both methods on the impedance of copper-rod and copper-strand conductors in place of the steel rail, with satisfactory agreement between them. Having thus obtained, after many trials, two fairly consistent methods of measurement, the Sumpner dynamometer method was finally selected as the best adapted to the local testing conditions, reserving the alternating-current potentiometer for occasional checks. Although this dynamometer method is theoretically subject to errors of extra skin effect, due to harmonics in the rail current and voltage waves, this error was not found to be serious. In the first place, the waves of rail current and voltage have not been very distorted, and, in the second place, the average dynamometer action is zero between a current of fundamental frequency in one coil and a current of any harmonic frequency in the other. Moreover, the harmonic component actions, being subject to differential distortion in phase by the reactances in two-coil circuits, are likely to be diminished in effect.

* The Sumpner dynamometer method has the disadvantages (1) that it is not a null method and (2) that it is not free from the effects of harmonics (*Phil. Mag.*, vol. 20, 1910, p. 309).

The Manganin Strip.—In order to supply a working p. d. in phase with the rail current, a manganin resistance strip was employed in the rail circuit, marked *S* in Fig. 3, and provided with two pairs of potential terminals, one across 2788 microhms, and the other across 933 of these microhms. This strip is made of two separate parallel plates of manganin 58.3 cm. (23 inches) long, 10.2 cm. (4 inches) broad, and 1.3 mm. (0.05 inch) thick, separated by mica insulation 1 mm. (0.04 inch) thick; so that the resistor is in the form of a very flat loop with the going and return conductors separated only by a sheet of mica. This strip was supported horizontally in a bath of oil, to keep it cool, when carrying currents above 400 ampères.

Direct-current Resistance Measurements.—In order to determine the skin-effect resistance ratio, it was necessary to measure the direct-current resistance of each rail at various times during a series of observations, and also the temperature coefficient of the rail's resistivity. This was done by direct-current potentiometer measurements in the usual way.

Temperature Measurements of the Rails.—The temperature of the rail was observed by thermometer, both before and after the measurement of impedance, at each current-strength in a test series. The thermometer was laid upon the rail, and had its bulb protected with a pad of putty. The rail currents above 100 ampères appreciably affected the temperature of the rail. Rail currents of about 750 ampères, during the time of application necessary for the measurements, sometimes raised the rail temperatures to 20° C. above that of the surrounding air. In order to avoid unduly large changes of temperature during a test, the highest current-strength was first applied, for a sufficient length of time to reach substantially constant temperature before the first measurement was made, after which the rail was allowed to cool off slowly as the testing current strengths were successively reduced.

Method of Connecting the Main Leads to the Ends of the Rail.—The rail ends had a hole of about 2 cm. ($\frac{13}{16}$ inch) diameter about 7.5 cm. (3 inches) from the ends. The web of the rail was scraped and cleaned near these holes, and copper lugs clamped firmly against the web by steel bolts passing through the holes. The contact resistance at these junctions was sufficiently low to prevent the junctions from getting unduly hot.

Situation of Potential Leads with Respect to Rail Circuit.—In measuring, by potentiometer, the direct-current potential difference between a pair of terminals on a rail, the disposition of the potential leads with respect to the rail circuit is of no material consequence, assuming that proper insulation is maintained. In measuring alternating-current potential differences, however, the disposition of the potential leads with respect to the rail circuit becomes of great importance, since the mutual inductance between these circuits will cause an induced electromotive force to be developed in the potential circuit over and above that due to the vector IZ drop sought, where I is the current and Z the rail impedance. At first thought it might be supposed that the simplest way to obtain the pure IZ drop in the rail would be to carry the insulated potential wires close along the web of the rail, and thence, by a twisted pair, from the middle. Actual trial, however, showed that the mutual inductance correction in the latter case was not only large, but uncertain, being practically beyond computation. By placing the potential leads in the form of a rectangle, as shown in Fig. K, Appendix III, the mutual inductance correction was rendered definite and susceptible of computation. By suitably selecting the sides of the rectangle, the resulting mutual-inductance correction can, by trial, be made small. The potential leads were then maintained permanently in this position during the progress of the work. The principal formula for deriving the correction is worked out in Appendix III.

Any error made in the mutual-inductance correction would clearly not affect the skin-effect resistance ratio R'/R, but would affect the values of the inductance L'. The effect of the error would be to alter the value of L' by a constant quantity throughout. If only the changes in L' with frequency and current are studied, such an error becomes eliminated. It was thought desirable in this research to determine the correction (Appendix III), so as to arrive at the best available values for L'.

Corrections for Temperature.—As has already been mentioned, the temperature of the rails tested was appreciably raised when the rail current exceeded 100 ampères, and even with short applications of 750 ampères the rail temperature was frequently raised 20° C. The resistivity temperature coefficient of the steel forming the rail was in each case measured by taking a series of continuous-current rail-resistance measurements, by potenti-

TABLE I.

Data Concerning Steel Rails Tested.

Rail Number / Type		96A P.R.R. standard track	100 N.Y. N.H. & H. standard track	163 A.R.A. type A. track	175 N.Y.C. R.R. standard track	161 A.R.A. type B. track	162 A.R.A. type B. track	170 A.R.A. type A. track	600 A. S.C.E. standard track	174 track	-51 A S.C.E. standard track	702 N.Y.C. R.R. standard contact	871 type D. contact
Linear mass	lbs./yard	100	100	100	100	100	90	90	60	70	80	69.3	86.5
	kg./m.	50	50	50	50	50	45	45	30	35	40	34.6	43.3
Cross-sectional area	sq. in.	9.8	9.8	9.8	9.8	9.8	8.8	8.8	5.88	6.86	7.84	6.79	8.48
	sq. cm.	63.2	63.2	63.2	63.2	63.2	56.9	56.9	37.9	44.3	50.5	43.8	54.6
Perimeter of cross-section	in.	22.6	24.4	24.3	24.4	23.0	21.5	22.7	18.8	18.7	21.7	15.2	21.0
	cm.	57.4	62.0	61.7	62.0	58.4	54.6	57.5	47.8	47.5	55.1	38.6	53.4
Approximate relative distribution of sectional area	head	0.41	0.41	0.37	0.44	0.40	0.40	0.36	0.41	0.41	0.42	0.4	0.34
	web	0.19	0.24	0.23	0.26	0.19	0.19	0.24	0.23	0.18	0.21	0.2	0.11
	base	0.40	0.35	0.40	0.30	0.41	0.41	0.40	0.36	0.40	0.37	0.4	0.55
Length of rail between potential contact points	ft.	30	30	30	30	30	30	30	30	30	30	30	30
	cm.	914	914	914	914	914	914	914	914	914	914	914	914
Resistance of tested length to continuous currents at 20° C. microhms		305.6	319.2	322.3	312.3	223.9	329.7	334.0	428.8	420.5	367.7	281.2	230.5
Resistivity at 20° C. absohm-cm., ρ_{20}		21100	22100	22300	21600	15500	20500	20800	17800	20350	20300	13500	14300
Temperature coefficient of resistivity at 20°C., α_{20}		0.00329	0.00274	0.00272	0.00265	0.00391	0.00356	0.00321	0.00350	0.00345	0.00295	0.00474	0.00458
Maximum skin effect	V_{60}	9.25	9.0	9.0	9.0	15.65	9.5	8.6	9.1	9.17	8.25	16.35	22.0
resistance ratio R'/R	V_{25}	6.08	5.65	5.65	5.65	10.10	6.1	5.6	5.85	6.05	5.35	10.92	13.4
Ratio, $\frac{V_{60}}{V_{25}}$		1.52	1.59	1.59	1.59	1.55	1.56	1.54	1.56	1.51	1.54	1.50	1.64
Square root of ratio of actual test frequencies		1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
Effective area of cross-section at maximum skin effect, square centimetres	S_{60}	6.83	7.02	7.02	7.02	4.04	6.0	6.6	4.2	4.85	6.1	2.7	2.48
	S_{25}	10.4	11.2	11.2	11.2	6.26	9.3	10.2	6.5	7.35	9.45	4.0	4.07
Effective depth of penetration in mm. at maximum skin effect	S_{60}	1.2	1.1	1.1	1.1	0.7	1.1	1.15	0.9	1.0	1.1	0.7	0.47
	S_{25}	1.8	1.8	1.8	1.8	1.07	1.7	1.75	1.35	1.55	1.7	1.04	0.76
Observed r. m. s. current in rail at maximum skin effect, ampères	I_{60}	700	800	800	800	390	600	700	450	505	850	280	160
	I_{25}	750	800	800	800	380	670	700	480	540	800	270	140
Computed mean corresponding magnetic intensity around perimeter	H_{60}	15.3	16.2	16.3	16.2	8.4	13.8	14.15	11.8	13.75	19.4	9.1	3.76
	H_{25}	16.4	16.2	16.3	16.2	8.2	15.4	14.15	12.6	14.5	18.2	8.8	3.30
Permeameter $\mu_{max.}$		.....	480	.....	432	970	.....	.....	.....	.....	.....	.....	2535
at H		.....	16.0	.....	16.2	7.5	.....	.....	.....	.....	.....	.....	2.9
Computed skin-effect resistance ratio R'/R	V_{60}	.....	7.48	.....	7.01	12.12	.....	.....	.....	.....	.....	.....	21.62
	V_{25}	.....	4.83	.....	4.53	7.83	.....	.....	.....	.....	.....	.....	13.62

TABLE II.

Observations on and Results for Sample Rail No. 174, Maryland Steel Company, April 27, 1915.

Cross-section 6.86 sq. in. (44.3 sq. cm.) 70 pounds per yard (35 kg. per m.) Test frequency 60 ~.

Moving coil across strip			Moving coil across rail							
Rail temperature, ° C.	Deflection, D_S, cm.	Capacitance in series, microfarad	Deflection, D_R, cm.	Capacitance in series, microfarad	Deflection, D_X cm.	Total resistance in series, including M (ohms)	Rail current, r. m. s. ampères	Alternating-current rail resistance, R'_{20} microhms	$\frac{R'_{20}}{R_{20}}$	Total rail inductance, millihenrys
33.5	43.68	0.0804	45.98	0.0200	43.42	214900	767.5	3775	8.98	0.01622
38.5	44.72	0.0905	46.03	0.0220	46.22	182400	732.5	3714	8.84	0.01609
40.7	42.80	0.1002	46.10	0.0250	42.92	171400	680.0	3762	8.95	0.01625
39.7	41.93	0.1202	45.52	0.0301	39.95	151400	615.4	3788	9.01	0.01635
37.8	43.92	0.1505	44.77	0.0351	40.60	125000	562.6	3841	9.14	0.01639
35.2	47.23	0.2008	41.15	0.0402	41.00	100100	505.2	3857	9.17	0.01646
32.9	43.05	0.2208	42.28	0.0503	42.25	80060	459.8	3838	9.13	0.01637
30.0	42.30	0.2711	46.68	0.0703	44.83	60060	411.2	3830	9.11	0.01629
26.7	43.60	0.3529	41.07	0.0804	42.78	50060	366.2	3762	8.94	0.01633
11.9	45.33	0.0604	47.47	0.0503	42.57	100100	302.0	3593	8.55	0.01600
13.3	41.23	0.0804	47.72	0.0804	40.87	70060	249.7	3292	7.83	0.01586
13.7	44.08	0.1303	44.78	0.1303	45.65	40060	202.6	2775	6.83	0.01526
14.0	41.57	0.2220	42.57	0.2723	44.02	22060	150.7	2363	5.60	0.01464
14.0	43.98	0.6038	45.40	0.9060	39.10	9060	94.1	1865	4.43	0.01375
0	I	II	III	IV	V	VI	VII	VIII	IX	X

The temperature of the rail during the test varied from 40° C. with the high currents to 12° C. with the low currents. The direct-current resistance of this rail at 20° C. was found, by potentiometer, to be 420.5 microhms = 14.02 microhms per foot = 46 microhms per metre, corresponding to a resistivity of 20,350 absohm-cm.; and the temperature coefficient of resistivity, from and at 20° C., is 0.00345 per degree C.

ometer, at different observed temperatures. The mean values of the temperature coefficient so obtained are indicated in Table I. They range from 0.00265 in the harder steels, to 0.00474 in the soft, higher-conductivity steel of the contact rails. In order to be strictly comparative, the measurements should all be taken with the rails at one and the same temperature of reference, since the skin effect varies appreciably with the resistivity. Since, however, it was not practicable to keep the rails at such a reference temperature, either on different days or with different current-strengths on the same day, the observed rail resistances R' have all been reduced to the reference temperature of 20° C. by means of the ordinarily used formula:

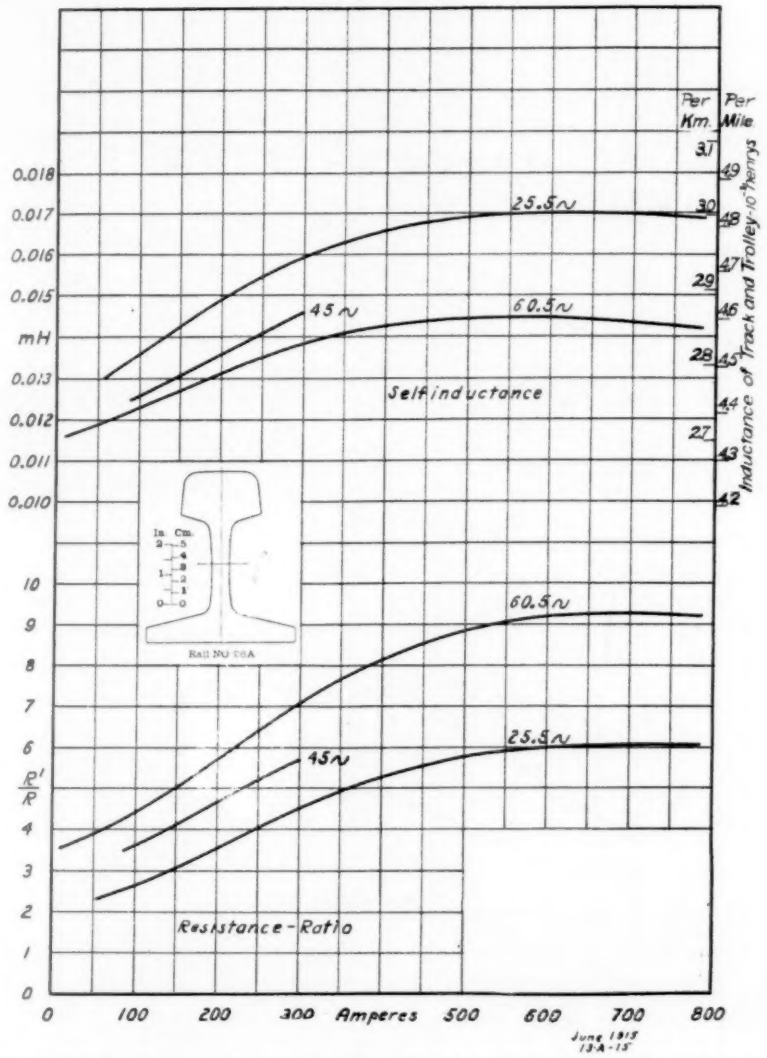
$$R'_{20} = R'_T / \{ 1 + a_{20} (T - 20) \} \quad \text{ohms} \quad (1)$$

where T was the rail temperature in degrees Centigrade at the time of the test, and a_{20} the resistivity temperature coefficient as found for this reference temperature. The results thus reduced were found to be fairly consistent, although the full temperature correction, including skin-effect variation, would be much more complicated.

Discussion of Results.—Table II gives a sample set of observations on one rail, taken by the Sumpner dynamometer method. The fixed coils of the dynamometer were conducted to the manganin shunt throughout the test, in the manner indicated in Fig. E. The flux quadrature compensation was adjusted for each alternating-current strength, in the manner described in Appendix I. Column I gives the full double deflection in scale cm. between + and −. The temperature of the rail during the test varied from 40° C. with the high currents, to 12° C. with the low currents. The direct-current resistance of this rail at 20° C. was found, by potentiometer, to be 420.5 microhms = 14.02 microhms per foot = 46 microhms per metre, corresponding to a resistivity of 20,350 absohm-cm.; and the temperature coefficient of resistivity, from and at 20° C., is 0.00345 per degree C.

Column X gives the total self-inductance of 30 feet (9.14 metres) of the rail in millihenrys. This is the inferred self-inductance to infinity, on the assumption that it includes all of the internal and external flux linked with the rail and due to the rail current in a rectangle based on 30 feet (9.14 metres) between potential points and extending radially to infinity.

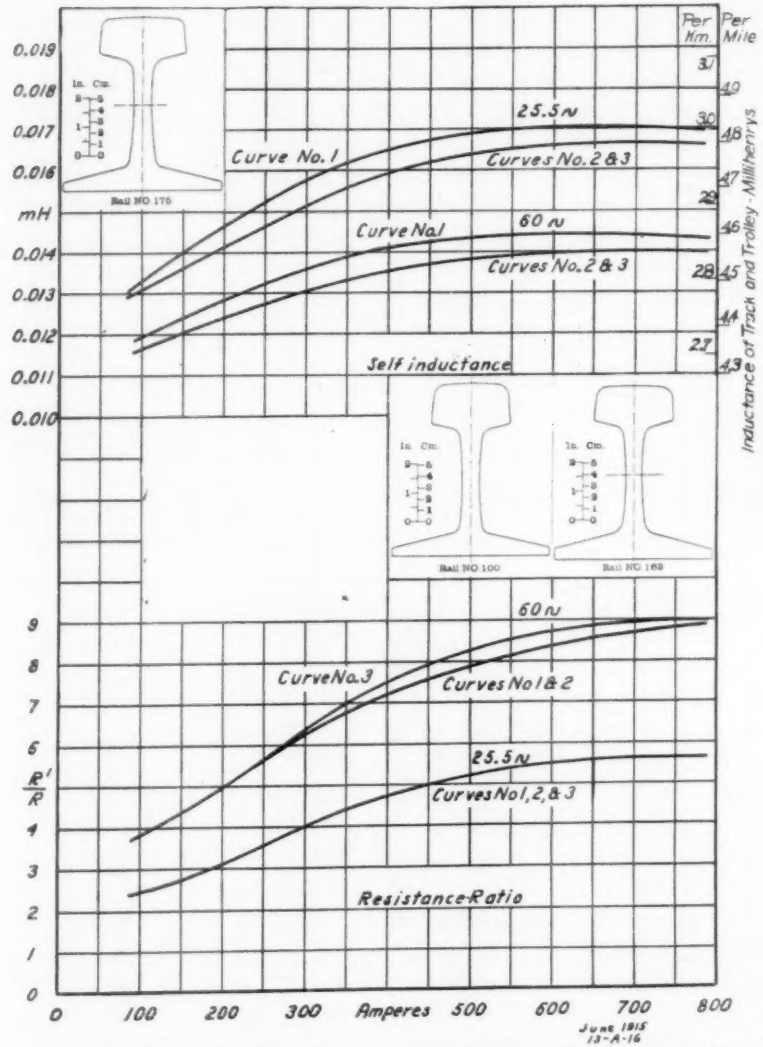
FIG. 5.



Curves of resistance-ratio and self-inductance rail No. 96-A. Study of skin effect in steel rails.

The results of the observations are presented in Figs. 5 to 10 inclusive. In all of these figures the abscissas are in r. m. s. ampères flowing through the rail under test. There are two sets of ordinates. The lower set is in each figure the skin-effect

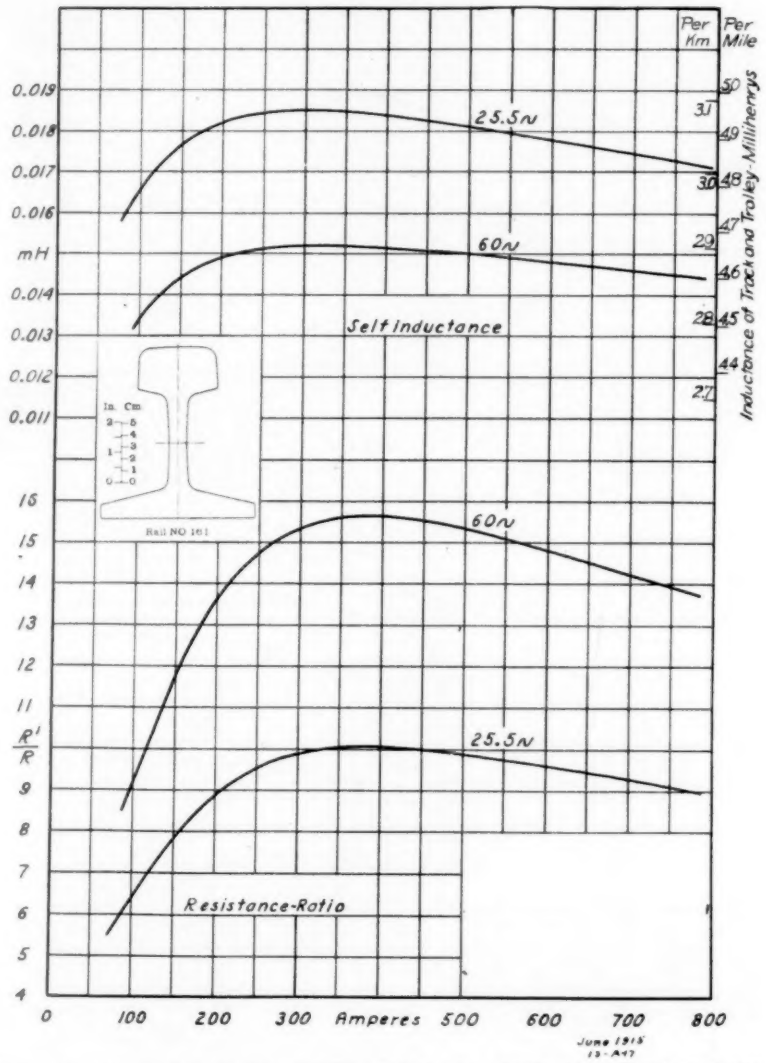
FIG. 6.



Curves of resistance-ratio and self-inductance. Rail No. 100, curve No. 1. Rail No. 163, curve No. 2. Rail No. 175, curve No. 3. Study of skin effect in steel rails.

resistance ratio R'/R; or the ratio of the apparent resistance of the rail in the presence of skin effect (reduced to 20° C.) to the resistance which it offers to continuous current from a storage battery at 20° C. The upper set of ordinates gives the inductance of the

FIG. 7.

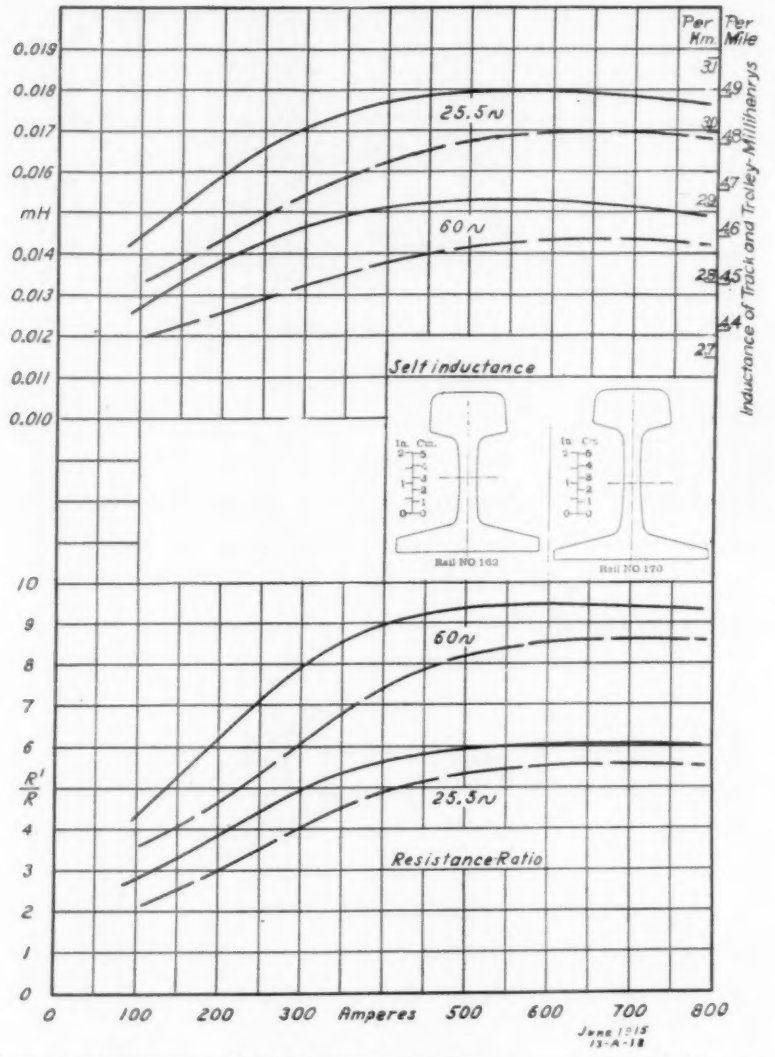


Curves of resistance-ratio and self-inductance. Rail No. 161. Study of skin effect in steel rails.

rail between contact points (914 cm.) in millihenrys, as referred to infinite flux radius. The total linear inductance of the rail L_1' is obtainable from these values by dividing with 914.

It will be seen that the skin-effect resistance ratio R'/R com-

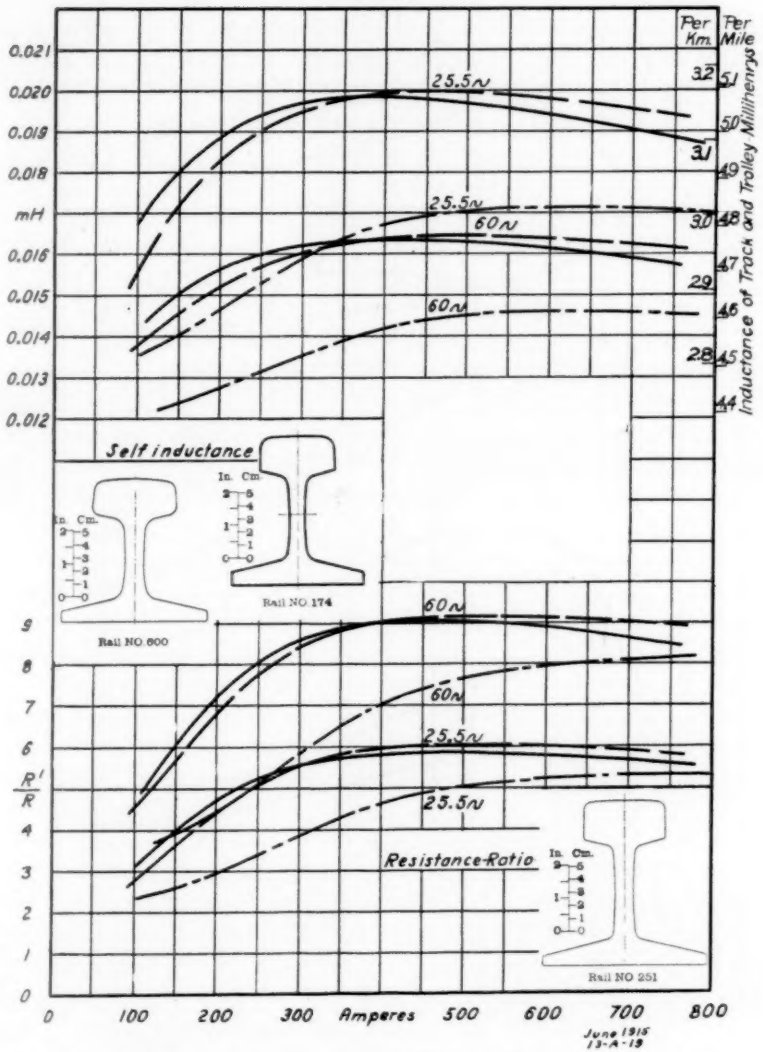
FIG. 8.



Curves of resistance-ratio and self-inductance. Rail No. 162 ——. Rail No. 170 ——.
Study of skin effect in steel rails.

mences with feeble rail current, at a relatively low value, increases when the current is increased, and, in nearly all cases, reaches a maximum value within the limits of 800 r. m. s. ampères. Similar remarks apply to the rail inductance L_1'. The skin-effect

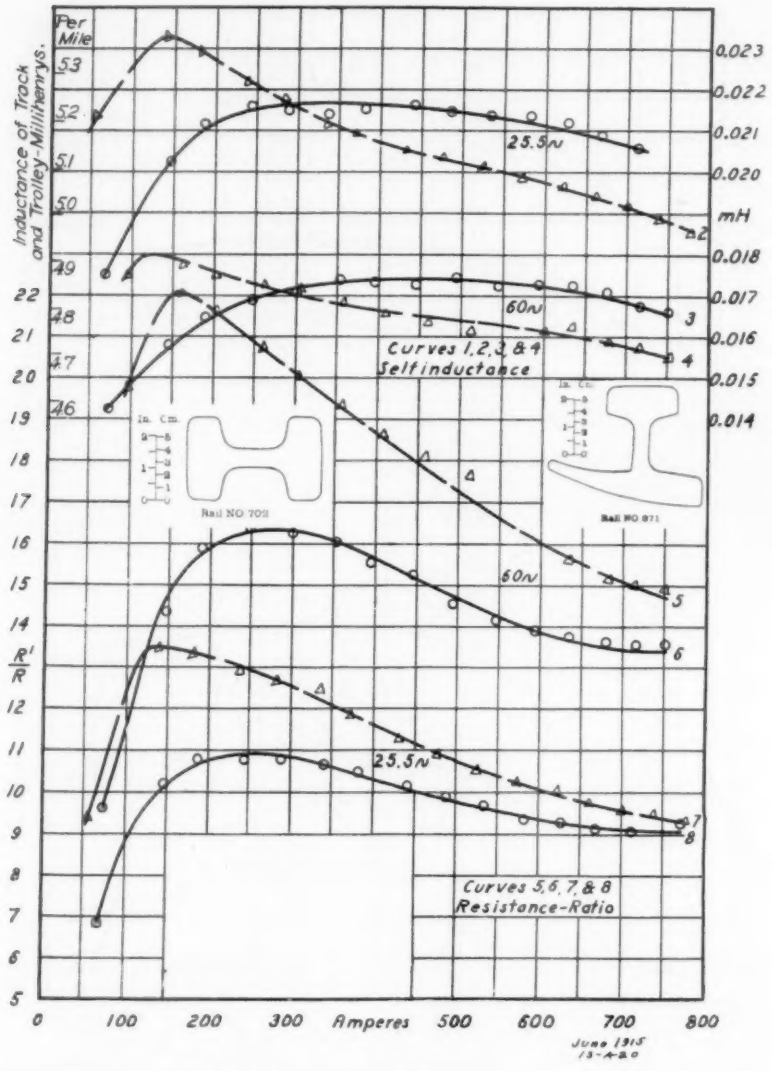
FIG. 9.



Curves of resistance-ratio and self-inductance. Rail No. 600 ———. Rail No. 174 — —. Rail No. 251 — — —. Study of skin effect in steel rails.

resistance ratio is greater at 60 ∞ than at 25 ∞, as might be expected; whereas the rail inductance L_1' is greater at 25 ∞ than at 60 ∞, although the rail reactance $L_1'\omega$ would always be greater at 60 ∞ than at 25 ∞.

FIG. 10.



Curves of resistance-ratio and self-inductance. Rail No. 702 -o——o-. Rail No. 871 -Δ— —Δ-.
Study of skin effect in steel rails.

The rise of skin-effect resistance to a maximum at a certain value of the rail current, is attributable to the variable permeability of the steel, which reaches a maximum at a certain value of the magnetizing force H, depending on the magnetic quality

of the steel, the effective skin penetration depth being changed accordingly. This phenomenon of a maximum impedance in steel prisms to a particular current-strength has been known experimentally at least as far back as 1893.*

Fig. 10 shows the resistance ratios and inductances of two soft steel contact rails. It will be noticed that the resistance ratio of No. 871 rises to 22; *i.e.*, that its alternating-current linear resistance at 60 ∞ is 22 times its direct-current resistance at the same temperature (20° C.). At 25.5 ∞, the resistance ratio of this rail is 13.5. Not only are these resistance ratios relatively large, but they occur at relatively small rail currents (150 r. m. s. ampères) and corresponding values of H at the perimeter (3 gilberts/cm.). This is attributable to the relatively large values of conductivity (7×10^{-5} abmho/cm.) and permeability (2500 gausses per gilbert/cm.). The equivalent penetration depth of the alternating current at this maximum permeability and at 25.5 ∞ is only 0.076 cm.; so that very little of the steel is utilized electrically.

On the upper right hand of each figure is the computed scale of linear inductance of the trolley wire and one track as deduced in Appendix II. The linear inductance of the system exceeds in one case 5 millihenrys per mile.

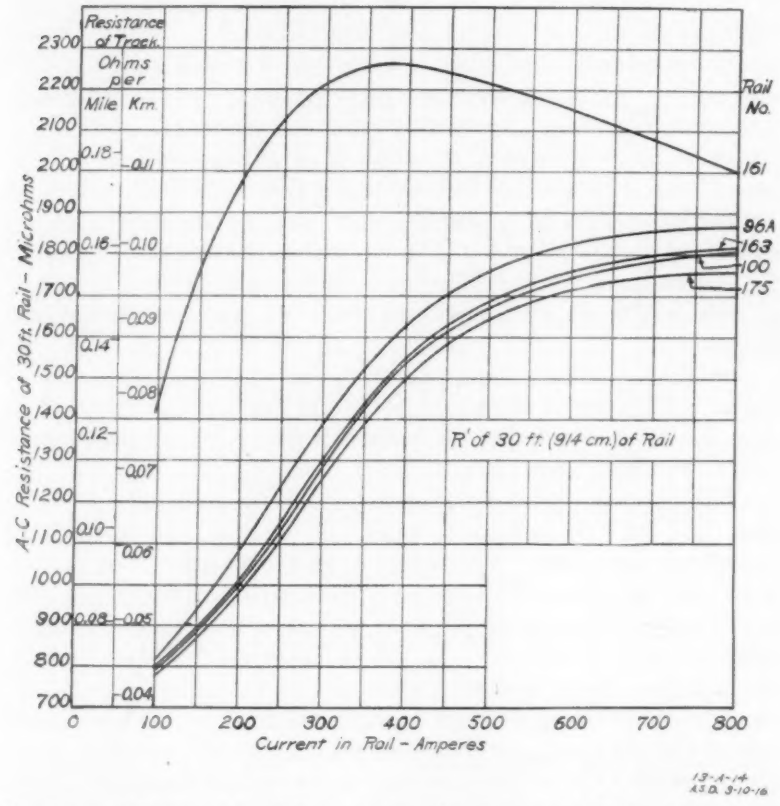
Fig. 11 shows the total alternating-current resistance R' in 30 feet (914 cm.) of each of the track rails at 25.5 ∞ to the scale of microhms ordinates. The scale is also repeated in ohms per mile and ohms per kilometre of a track of two rails in parallel, assuming perfect bonding but no copper reënforcement, also negligible leakance to ground. It will be observed that rail No. 161 has a higher linear resistance than any of the others, in spite of the fact that its conductivity is relatively high. The high alternating-current resistance is attributable to a small equivalent penetration depth ($\delta = 0.107$ cm. at 25.5 ∞), which in turn is due to the large product of γ and μ. To direct currents, this rail would offer the lowest resistance among all the track rails tested.

It is shown in Appendix IV that the resistance-ratio R'/R for a rail can be deduced from the measured direct-current values of its conductivity γ and permeability μ, for any assigned frequency, subject to a certain range of inaccuracy due to errors of permeability and shape, the actual effective alternating-current permeability dif-

* Bibliography No. 2.

fering to some extent from that observed by direct-current permeameter, and the shape of the rail involving edge effects owing to departure from a simple cylinder. The permeability and shape correction factors which must be applied to the computed values of R'/R, in order to arrive at the actual values, are at present

FIG. 11.

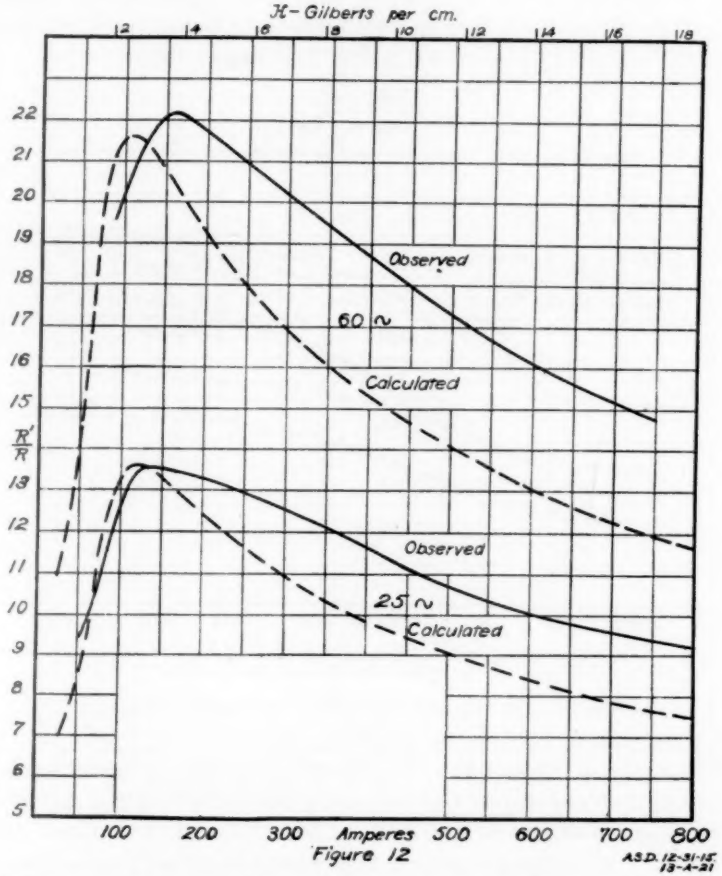


Comparison of R' at 25.5 ∞. Rails number 161, 96A, 163, 100, 175. Study of skin effect in steel rails.

beyond direct calculation, but may be estimated from experimental observations. Thus, in Fig. 12, the observed and computed values of R'/R are given for the contact rail No. 871 at the two test frequencies 60 ∞ and 25 ∞. The computed values are obtained by (65), from measured direct-current conductivity γ and direct-current permeameter μ of a rod 38 cm. (15 inches)

long and 1.25 cm. (0.49 inch) in diameter cut from the head of this rail. It will be seen that, at or near 150 ampères r. m. s., the observed values of R'/R reach a maximum, and are in fairly close agreement with the calculated values; so that the correction factor

FIG. 12.

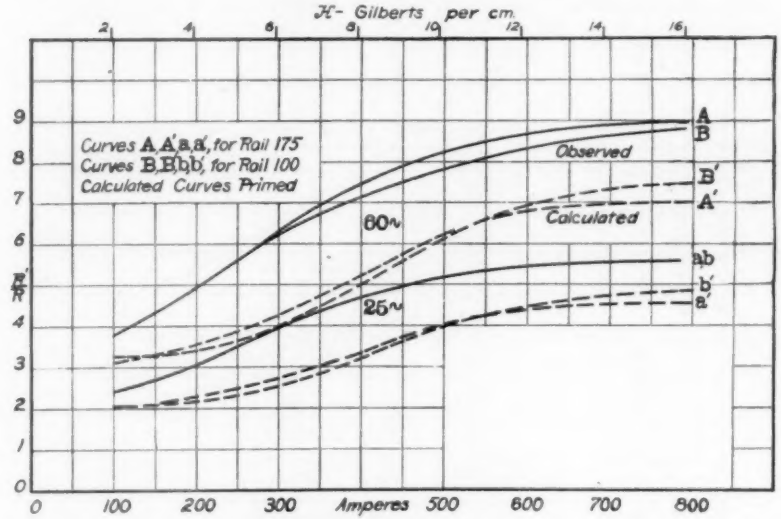


Rail 871. Curves of resistance ratio calculated from infinite strip formula and D-C values of permeability. Study of skin effect in steel rails.

for 25 ∾ and 125 ampères is 1.0. At higher current-strengths, however, the observed resistance ratio rises above the computed resistance ratio and the correction factor becomes greater than unity. For 750 ampères of rail current at 60 ∾, it is 14.8/12 =

1.233, and at 25 ∞ it is 9.38/7.65 = 1.23. For this rail with its particular values of conductivity and permeability, the correction factor varies between 0.9 and 1.23, according to the strength of current. Since the resistance ratio R'/R is a maximum for that current-strength and value of H at which the effective permeability is a maximum, it is ordinarily of greater importance to determine the correction factor at this maximum point, as it is likely to be the condition of greatest power loss in practice.

FIG. 13.

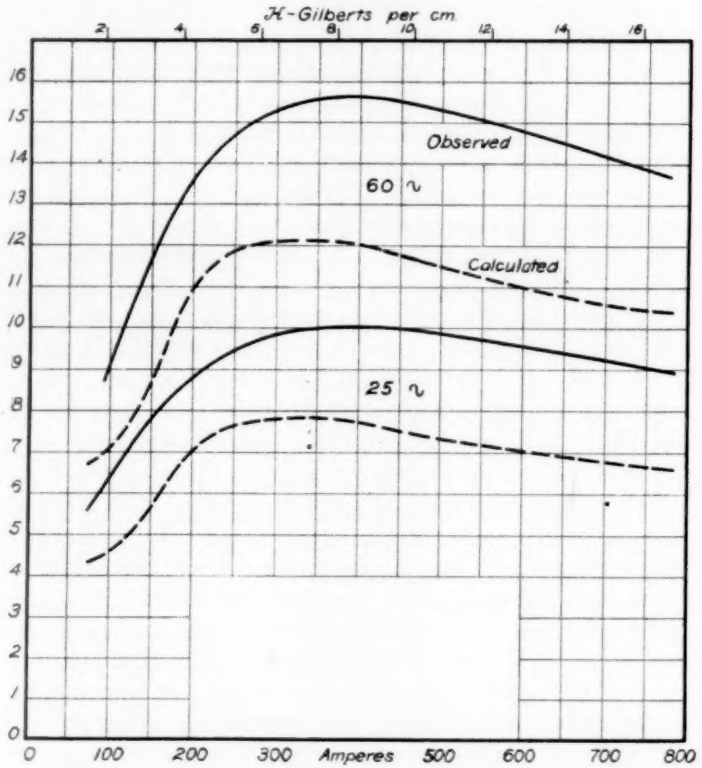


Curves of resistance ratio calculated from infinite strip formula and D-C values of permeability. Study of skin effect in steel rails.

Fig. 13 shows corresponding curves of observed and computed resistance ratios for low-permeability track rails 175 and 100, at 60 ∞ and 25 ∞. Here the maximum values are not exceeded at the maximum current of 800 ampères, and the correction factor is appreciably over 1.0 throughout. Thus on rail 175, at 60 ∞, this factor is 1.23 at 100 ampères, and attains 1.47 at 350 ampères. At 25 ∞, the maximum value of the correction factor is 1.45 at 350 ampères. The samples of steel from which the calculated values were obtained were rods cut from both sides of the head and also from the flange. The values of γ and μ obtained in rods from these different positions in the section of one and the same rail were found to be in satisfactory agreement.

Fig. 14 shows corresponding curves of observed and computed resistance ratios for the medium-permeability track rail No. 161. Here the maximum ratios are reached near to 350 ampères. The maxima of the computed curves agree fairly well with the maxima of the observed curves, and this is a property found in all of the

FIG. 14.



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Rail 161 curves of resistance ratio calculated from infinite strip formula and D-C values of permeability. Study of skin effect in steel rails.

cases investigated. The correction factor for 400 ampères and 60 ∞ is 15.6/12.1 = 1.30, and at 25 ∞ it is 10.05/7.75 = 1.30. The computed values in this case were obtained from observations of γ and μ on one rod 38 cm. long and 1.25 cm. in diameter, cut from the head of the rail.

Measurements of Conductivity.—The sample steel rod was milled from the rail and then turned in the lathe. It was finally finished to the required diameter (1.25 cm.) by filing in the lathe. The conductivity of this rod was determined at a series of different temperatures between 10° C. and 25° C., by direct-current potentiometer measurement, using such strengths of storage-battery current as served to bring the temperature of the rod up to the required amount. Both the resistivity and its temperature coefficient found in this way agreed satisfactorily with the values obtained previously in the rail tests as already described.

Measurements of Permeability.—The sample steel rod from the rail under investigation was tested in a Burrows permeameter,* which gave satisfactory results. In one case the 38-cm. rod, after being tested in this permeameter, was cut down in the lathe to a diameter of 0.6 cm. and tested in a Koepsel permeameter.† The permeability of the material as obtained from the Koepsel permeameter was a few per cent. less throughout than that obtained in the Burrows permeameter, which difference might be attributed to the relatively greater effect of hardening machine treatment on the sample of smaller diameter. It should be observed from formula (65) that 1 per cent. error in the measurement of permeability only affects the resistance ratio R'/R by 0.5 per cent.

Technic Recommended for Predetermining Rail Resistance Ratios.—According to the results here reported, it is sufficient for the determination of the maximum skin-effect resistance ratio R'/R in a steel rail to measure the values of γ and μ in a sample rod of the same material, which, by formula (65), gives the computed value of R'/R for a given frequency and series of alternating-current rail-current strengths, assuming that the measured direct-current permeabilities do not appreciably differ from the actual effective alternating-current permeabilities at these currents, including the effects of hysteresis, and also that the rail has a simple circular or cylindrical cross-section. In order, then, to correct for the errors of permeability and shape, a correction factor should be applied to the computed ratio. This correction factor appears in the results here reported to have varied in track rails, at maximum permeability, from 1.2 to 1.3. It is probably advisable to use the latter value for security. In other words, the

* Bibliography No. 18.

† Bibliography No. 30.

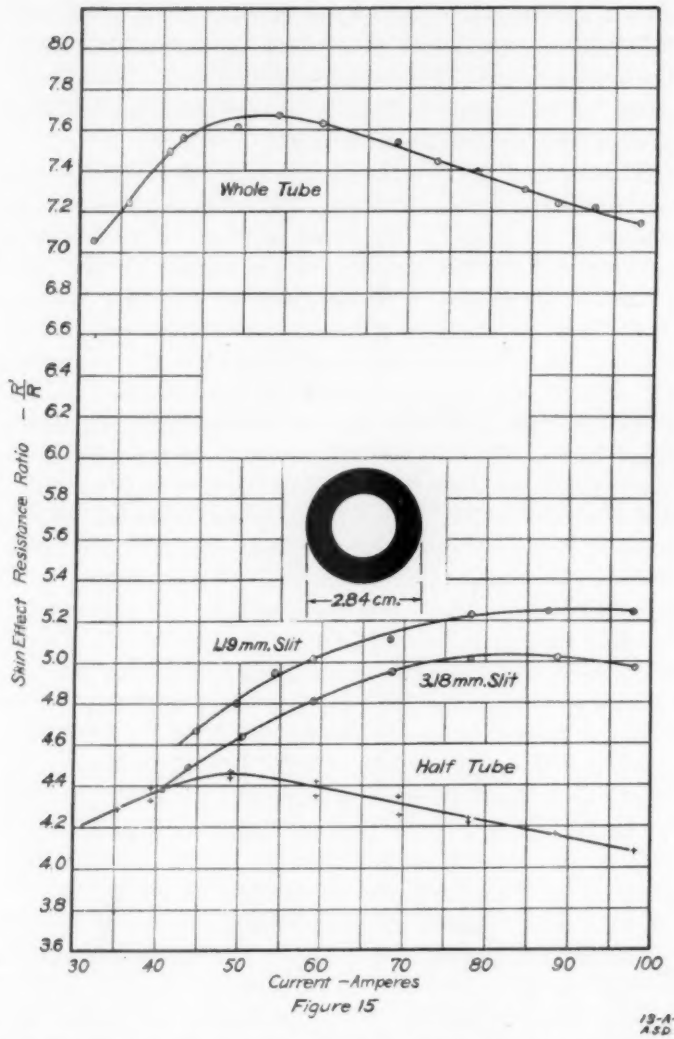
computed value of R'/R should be increased by 30 per cent. for the unknown permeability and shape errors. The result may then be taken as the maximum skin-effect resistance ratio of the rail, at the temperature and frequency considered. At all other rail currents, the resistance-ratio and the resistance per kilometre will be less, at constant rail temperature.

Best Shape of Rail Section for Conducting Purposes.—In steel track rails, mechanical considerations are necessarily paramount for determining the shape of the cross-section. For conducting rails, however, where the stresses to be supported are much smaller, consideration may well be given to the best form of cross-section for conducting purposes. Formula (68) shows that, provided there is sufficient depth beneath the surface in which the electric and magnetic fluxes can deploy—say, 4δ for a single surface of slab, or 8δ between opposite surfaces of a strap—the effective alternating-current conductance, in the presence of skin effect, depends upon the ratio P/S, or the perimeter per square centimetre of cross-section. This would point to the use of a flat strap as the best type of conductor. The edge effect in such a strap, however, militates against its use, to say nothing of its clumsiness and oxidizability. For these reasons it is preferable to employ a steel tube or hollow cylinder. In practice, in order to improve the mechanical brush-contact surface, the tube should be flattened, at least on the contact side, and sharp edges in the contour avoided. If the section is simply tubular, of thickness exceeding 4δ cm., the interior surface of the tube is prevented from carrying any appreciable alternating current. By slitting the tube, however, or by rolling a plate into the form of a nearly closed box beam, 8δ or more in wall thickness, both the internal and external surfaces of the hollow conductor become available.

To test this plan, a steel tube was employed 150 cm. long and of the cross-section shown in Fig. 15. The resistance ratio of this tube was found to be 7.66, for 60 ~, at 53 ampères r. m. s.* When a thin, longitudinal slit (1.19 mm. wide) was milled along this tube, the resistance ratio fell to 5.26, with the maximum at about 90 ampères. When the slot was widened to 3.18 mm., the ratio was observed to fall to 5.04 at 80 ampères. When the tube

* The resistance ratio computed by formula (65), from a sample rod of this steel, had a maximum at 53 ampères of only 6.45, representing a correction factor of 1.18 for hysteresis and permeability alone.

FIG. 15.



Skin effect resistance ratio for steel tube at 60 ∿. Outside diam. 2.84 cm.—6.35mm. wall.

was cut in half, by making an opposite longitudinal slot, the value fell to 4.46 at 48 ampères. The values of current at which the maxima are obtained correspond very fairly with the reciprocals of the effective perimeters in each case. Inserting the slot did not

double the effective alternating-current conductance, but did increase it in the ratio of $7.66/5.04 = 1.52$, the discrepancy being presumably attributable to magnetic leakage near or across the slit. It would appear, therefore, that the two half tubes, connected in parallel, would be a better joint conductor than the slotted tube, and would exceed the conductance of the unslotted tube in the ratio $7.66/4.46 = 1.72$.

It is hoped to investigate further this question of most economical conducting cross-section.

It should be pointed out that for a given shape of cross-section the effective alternating-current conductance of a rail depends upon both γ and μ, and not merely on one of these quantities. An increase in permeability may more than offset the advantage of an increase in conductivity γ. An ideal steel would have a very high conductivity associated with a very low permeability.

Chemical Analysis of Samples.—Table III gives the chemical analysis of the steel in the various rails tested.

TABLE III.

Chemical Contents of Rails Used in the Research on Skin Effect in Steel Rails.

Rail No.	Percentage Element						
	C	P	Si	Mn	Cr	Ni	S
* 96A	0.65	0.090	0.06	0.68	0.35	0.55	0.065
*100	0.55	0.090	0.08	1.08	0.30	0.60	0.095
*163	0.70		0.07	0.97	0.47	0.46	0.05
*175	0.60	0.124	0.08	0.83	0.30	0.45	0.07
*161-1	0.42	0.004	0.04	0.50	0.05	0.15	0.08
*161-2	0.68		0.09	0.65	0.31	0.51	0.095
*162	0.38	0.032	0.06	0.62	0.31	0.40	0.05
*170	0.40	0.004	0.05	0.43	0.085	0.12	0.04
600	0.59	0.032	0.122	0.67			0.044
174	0.37	0.065	0.032	0.40			0.070
251	0.74	0.035	0.063	0.34			0.072
702	0.11	0.113	0.020	0.36			0.091
871	0.17	0.132	0.025	0.51			0.099

* These tests were made by students in chemistry and are not equally reliable.

In conclusion, the authors desire to express their indebtedness to the courtesy of the Lackawanna Steel Company and the Maryland Steel Company for the use of the steel rails tested, also to Dr. G. A. Campbell for valuable suggestions on the manuscript.

SUMMARY OF CONCLUSIONS.

1. The maximum observed skin-effect resistance ratio among ten track rails, at 25 ∞, varied between 5.35 and 10.1, and in two contact rails between 10.92 and 13.4.

2. The maximum observed skin-effect resistance ratio was found to vary substantially as the square root of the impressed frequency between the limits of 25 ∞ and 60 ∞.

3. The effective skin depth of alternating-current penetration, at 25 ∞, among all the twelve rails tested, varied between 0.76 mm. and 1.8 mm.

4. The values of the mean superficial r. m. s. magnetic intensity H at which the maximum skin effect developed, were between the limits of 3.3 and 16.4 gilberts per centimetre. These were but little influenced by frequency, and were in good agreement with the values of H for maximum μ, as obtained by direct-current permeameter.

5. The best workshop method of measuring the skin effect in track rails was, in this case, found to be based on the use of a particular form of dynamometer.

6. The effective alternating-current conductance of a rail is, to a first approximation, inversely as the square root of the frequency, and, at a given frequency, is directly proportional to the perimeter, and to the square root of the ratio $\frac{\gamma}{\mu}$.

7. It is therefore, in general, useless to increase the conductivity γ of the steel in a rail if the permeability μ is thereby increased in the same or a greater ratio.

8. From the results here reported, it would seem that the skin-effect resistance ratio of a rail, to a given alternating-current frequency and current-strength, can be approximately predetermined from measurements of the conductivity γ and permeability μ of the steel, by applying an experimentally determined factor to cover edge effect and other discrepancies. This factor, which may be called the "edge-effect coefficient," appeared to be not more than 1.3 at the maximum skin-effect ratio.

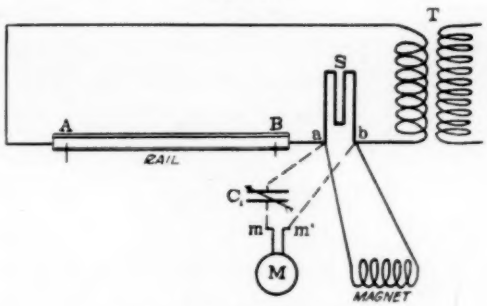
9. The best form of rail for current-carrying capacity should be one in which the effective perimeter is a maximum while allowing sufficient depth of surface. Among the worst forms are probably a thick solid prism and a cylinder. A hollow cylinder may be greatly improved by slitting it, so as to admit current to its interior surface.

APPENDIX I.

METHOD OF EMPLOYING THE SUMPNER DYNAMOMETER IN IMPEDANCE MEASUREMENTS.

The Sumpner dynamometer had one fixed coil A with 4000 turns of relatively fine insulated wire having 90 ohms resistance, and another fixed coil C, with 200 turns of coarser wire, having about 0.75 ohm resistance. The moving coil M has about 50 turns with about 60 ohms resistance, including leads and suspension. The fixed coils being provided with a laminated iron core, the moving coil swings in a relatively strong magnetic field, due to the mmf. of the fixed coils.

FIG. A.



Sumpner-dynamometer test connections.

Fig. A indicates the connections employed with the instrument connected across the manganin strip S to measure the p. d. across the terminals a, b, and therefore the current in the rail circuit. The current flowing through the magnet coils from the terminals a, b, under the impressed voltage $E_s = IS$, may be assumed, for the present, to produce an alternating magnetic flux in the air-gap, 90° in phase behind E_s. The branch circuit containing the moving coil M includes a small condenser, of pure capacity reactance so large that the resistance and inductive reactance in M are negligible with respect thereto. The current in M will therefore lead the impressed voltage E_s by substantially 90°, and will therefore be in phase with the air-gap flux-density B_s. The moving torque will therefore be

$$\tau_s = kI_{M_s}B_s \qquad \text{dyne perp. cms.*} \quad (2)$$

* Unit torque, in the C. G. S. system, is one dyne acting perpendicularly at a radius of one cm.

where k is a constant for the instrument, which can be determined from the use of a known voltage.

The current in the moving coil will be

$$I_{M_s} = jE_s c_s \omega \qquad \text{ampères} \angle \qquad (3)$$

and the flux density in the air-gap, assumed radial, is

$$B_s = -jk_1 E_s / \omega \qquad \text{gausses} \angle \qquad (4)$$

k_1 being a constant for the magnetic circuit of the instrument. Consequently

$$\tau_s = kk_1 E_s^2 c_s \qquad \text{dyne} \perp \text{cm.} \qquad (5)$$

and if the moving system has a unifilar suspension providing a resisting torque proportional to the scale deflection D cms.,

$$\tau_s = aD_s \qquad \text{dyne} \perp \text{cm.} \qquad (6)$$

where a is a constant depending on the elastic torsion of the suspension and on the scale. Equating the opposing torques,

$$kk_1 E_s^2 c_s = aD_s \qquad \text{dyne} \perp \text{cm.} \qquad (7)$$

or

$$E_s = \sqrt{\frac{aD_s}{kk_1 c_s}} = K\sqrt{\frac{D_s}{c_s}} \qquad \text{volts} \qquad (8)$$

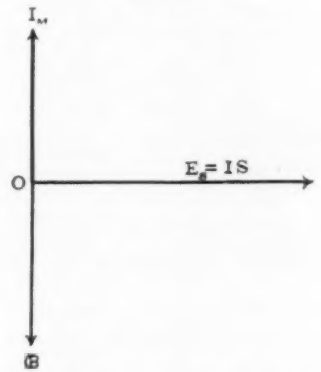
where $K = \sqrt{\frac{a}{kk_1}}$;

and

$$\frac{D_s}{c_s} = E_s^2 \cdot \frac{1}{K^2} \qquad (9)$$

The vector diagram of the case is presented in Fig. (B). OE_s is the alternating-current r. m. s. voltage across the terminals ab of

FIG. B.



Vector diagram of Sumpner-dynamometer phase relations.

the shunt, taken as at standard phase. OB is the flux density in the air-gap, assumed to be just 90° behind OE_s. OI_m represents the current in the moving coil M, advanced 90° ahead OE_s, by reason of the capacity reactance in its branch circuit.

If now the terminals mm' of the moving coil are transferred to the potential terminals AB of the rail, the flux density in the air-gap remains the same as before; but the current in the moving coil

FIG. C.

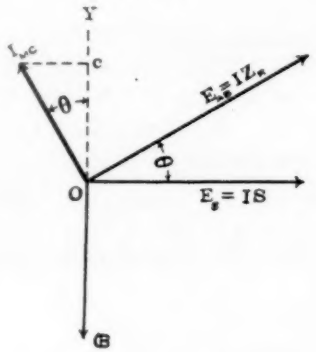
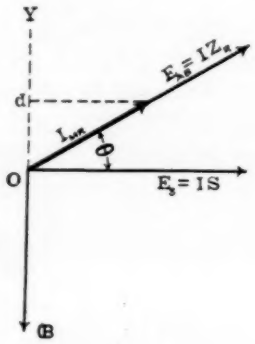


FIG. D.



Vector diagram of Sumpner-dynamometer phase relations.

is changed, both in magnitude and phase. Referring to Fig. C, let OE_{AB} be the vector voltage on the rail, advanced θ° ahead of the current I, according to the relation

$$E_{AB} = IZ\angle\theta = I(R' + jL'\omega) \qquad \text{volts}\angle \qquad (10)$$

The current in the moving coil OI_{MC} will be thrown 90° ahead of OE_{AB} owing to the presence of the condenser c_R in its circuit. The torque will then be

$$\tau_R = kI_{MC}\cos\theta . B_s \qquad \text{dynes T cm.} \qquad (11)$$

$$= kE_{AB}c_R\,\omega\cos\theta . k_1 E_s/\omega$$

$$= kk_1 E_{AB} E_s \cos\theta\, c_R \qquad \text{dynes T cm.} \qquad (12)$$

or proportional to the product of Oc. OB on the diagram. This torque produces a deflection

$$D_R = \tau_R/a \qquad \text{cm.} \qquad (13)$$

so that

$$\frac{D_R}{c_R} = \frac{kk_1}{a} . E_{AB} . E_s . \cos\theta = E_{AB} . E_s . \cos\theta \frac{1}{K^2} \qquad \frac{\text{cm.}}{\text{farad}} \qquad (14)$$

Dividing (14) by (9), we obtain

$$\frac{D_R}{c_R} \Big/ \frac{D_s}{c_s} = \frac{E_{AB} \cdot E_s \cdot \cos\theta}{E_s^2} = \frac{E_{AB} \cos\theta}{E_s} = \frac{IR'}{IS} = \frac{R'}{S} \quad \text{numeric} \quad (15)$$

If now a suitable non-reactive resistance R_M ohms is substituted for the condenser C_1 the current which will flow in the moving coil will be

$$I_{MX} = \frac{E_{AB}}{R_M} = \frac{IZ/\theta}{R_M} \quad \text{ampères} \angle \quad (16)$$

In Fig. D, OE_s is the voltage at standard phase across the shunt S, and OE_{AB} the voltage across the terminals AB leading the current by the angle $\theta°$. Then the current in the moving coil will be in phase with OE_{AB} and is indicated by OI_{MR}. The component Od, on the axis OY, will be $OI_{MR} \sin\theta$, and the torque will be

$$\tau_X = kI_{MX} \sin\theta B_s \quad \text{dynes} \perp \text{cm.} \quad (17)$$

$$= kk_1 \cdot \frac{E_{AB}}{R_M} \cdot \sin\theta \cdot \frac{E_s}{\omega} \quad \text{dynes} \perp \text{cm.} \quad (18)$$

$$= aD_X$$

where D_X is the scale deflection in this case.

Equating torques

$$D_X R_M = \frac{1}{K^2} E_{AB} \cdot \sin\theta \cdot \frac{E_s}{\omega} \quad \text{cm-ohms} \quad (19)$$

Dividing (19) by (9), we have

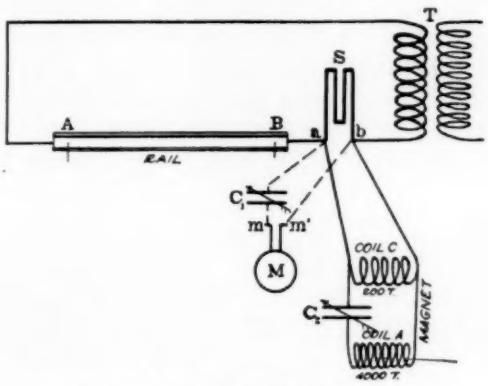
$$\frac{D_X \cdot R_M}{D_s/c_s} = \frac{E_{AB}}{E_s} \cdot \frac{\sin\theta}{\omega} = \frac{L'}{S} \quad \frac{\text{henrys}}{\text{ohms}} \quad (20)$$

It is therefore evident that, assuming the flux in the air-gap to be in quadrature with the voltage impressed on the alternating-current magnet, the quantities I, R'/S, and D'/S are found in terms of the three deflections, D_s, D_R, and D_X, and the corresponding impedances in the moving-coil circuits.

In the actual instrument, however, the magnetic flux and flux density B_s are not more than about 85° behind the impressed voltage in phase, as is shown by the fact that a deflection on the scale is produced when the magnet coil and the moving coil are connected in parallel to one and the same voltage E_s. In order to correct for this deviation, and bring the resultant magnetic flux density into strict quadrature with E_s, a condenser C_2 is

inserted in the 4000-turn coil A, as shown in Fig. E. This condenser has from 1 to 6 microfarads capacitance, according to the frequency and to the magnitude of E_s, which affects the hysteresis in the core. Its magnitude is adjusted by trial in such a manner

FIG. E.



Sumpner-dynamometer test connections.

that when the condenser C_1 is replaced by a resistance in Fig. E, no deflection is produced.

APPENDIX II.

THE LINEAR INDUCTANCE OF A SIMPLE SYMMETRICAL ELECTRIC-RAILROAD CONDUCTING SYSTEM, COMPRISING A LONG, STRAIGHT, UNIFORM TROLLEY WIRE, SUPPORTED AT A FIXED HEIGHT ABOVE THE CENTRE OF A TRACK FORMED BY TWO SIMILAR AND PARALLEL STEEL RAILS.

As a first step, the simpler and more familiar case may be considered of a single long trolley wire T (Fig. F) of radius ρ_0 cm., supported at a constant interaxial vertical distance d cm. above the equivalent centre of a single steel rail R. The permeability of the trolley wire is μ_0. The extra linear inductance of the trolley wire—*i.e.*, the inductance per cm., in so far as depends on flux collapsing upon the surface of the wire when its current is brought to zero*—is, by Neumann's formula,

$$L_{0e} = 2\left(\log_h \frac{2l}{\rho_0} - 1\right) \quad \frac{\text{external abhenrys}}{\text{wire cm.}} \qquad (21)$$

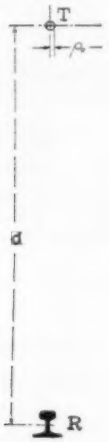
* "The Self and Mutual Inductance of Linear Conductors," by E. B. Rosa, *Bulletin of the Bureau of Standards*, vol. 4, No. 2, p. 301, September, 1907.

where l is the length of the trolley wire in cm., and logh signifies the hyperbolic or Napierian logarithm. This may be written

$$L_{0e} = 2 \operatorname{logh} \frac{2l}{\epsilon\rho_0} \qquad \frac{\text{external abhenrys}}{\text{wire cm.}} \qquad (22)$$

where $\epsilon = 2.718\ldots$ the Napierian base. The linear internal

FIG. F.



Cross-section of single rail and an overhead trolley wire.

inductance of a round wire of uniform permeability ($\mu_0 = 1$ for copper) is also well known to be

$$L_{0i} = \frac{\mu_0}{2} \qquad \frac{\text{internal abhenrys}}{\text{wire cm.}} \qquad (23)$$

The total linear inductance of the trolley wire, extending outwards to an indefinite distance from its axis, is therefore

$$L_0 = L_{0i} + L_{0e} = 2 \operatorname{logh} \frac{2l}{\epsilon\rho_0} + \frac{\mu_0}{2} \qquad \frac{\text{abhenrys}}{\text{wire cm.}} \qquad (24)$$

Moreover, the linear mutual inductance of the trolley wire and the rail, considering the latter as substantially equivalent to a parallel wire of dimensions small compared with the distance l, is *

$$M_{01} = 2 (\operatorname{logh} \frac{2l}{d} - 1) = 2 \operatorname{logh} \frac{2l}{\epsilon d} \qquad \frac{\text{abhenrys}}{\text{wire cm.}} \qquad (25)$$

* *Bulletin of the Bureau of Standards*, vol. 4, p. 306.

The linear inductance of the wire in the presence of the rail return conductor becomes, therefore,

$$L_{01} = \frac{\mu_0}{2} + 2\left(\log_h \frac{2l}{\epsilon\rho_0} - \log_h \frac{2l}{\epsilon d}\right) \quad \frac{\text{abhenrys}}{\text{wire cm.}} \quad (26)$$

$$= \frac{\mu_0}{2} + 2 \log_h \frac{d}{\rho_0} \quad \frac{\text{abhenrys}}{\text{wire cm.}} \quad (27)$$

This trolley-wire linear inductance to rail return can be computed with satisfactory precision, since any error in assigning the equivalent centre of the rail has ordinarily but little effect on the result.

Again, the linear internal inductance of the rail being written L_{1i} abhenrys per cm., the linear external inductance of the rail may be taken as

$$L_{1e} = 2 \log_h \frac{2l}{\epsilon\rho_1} \quad \frac{\text{abhenrys}}{\text{rail cm.}} \quad (28)$$

where ρ_1 is the equivalent radius of the rail, and a quantity not easy to assign precisely in practice. The linear total inductance of the rail is then outwards to infinity

$$L_1 = L_{1i} + 2 \log_h \frac{2l}{\epsilon\rho_1} \quad \frac{\text{abhenrys}}{\text{rail cm.}} \quad (29)$$

and, taking the mutual inductance to the trolley wire M_{01} of (25) into account, the linear total inductance of the rail in the presence of the return trolley wire is

$$L_{10} = L_{1i} + 2 \log_h \frac{d}{\rho_1} \quad \frac{\text{abhenrys}}{\text{rail cm.}} \quad (30)$$

The linear total inductance of the loop formed by trolley wire and rail together is then

$$L = L_{01} + L_{10} = \frac{\mu_0}{2} + L_{1i} + 2 \log_h \frac{d}{\rho_0} + 2 \log_h \frac{d}{\rho_1} \quad \frac{\text{abhenrys}}{\text{loop cm.}} \quad (31)$$

If the linear total inductance of the rail outwards to infinity (L_1) can be measured experimentally for a particular rail length l cm., then the corresponding value to the trolley wire return conductor is

$$L_{10} = L_1 + 2 \log_h \frac{d\epsilon}{2l} \quad \frac{\text{abhenrys}}{\text{rail cm.}} \quad (32)$$

The linear loop inductance can thus be determined for any assigned value of the trolley-wire vertical distance d, if the actual linear inductance L_1 of the rail can be correctly measured outwards to infinity for a known rail length of l cm.

If now we consider the practical case of a trolley wire supported over a line midway between two parallel rails (Fig. G), distant b cms. apart on equivalent centres, then it is easily shown that if the mutual inductance between the two rails with respect to the trolley wire return is defined as:

$$M_{12} = 2 \log_h \frac{d}{b} \qquad \frac{\text{abhenrys}}{\text{rail cm.}} \qquad (33)$$

the linear total inductance of the system, formed by the trolley wire with the two rails as joint return conductors, is

$$L = L_{01} + \frac{L_{10}}{2} + \frac{M_{12}}{2} = \frac{\mu_0}{2} + 2 \log_h \frac{d}{\rho_0} + \frac{L_{11}}{2} + \log_h \frac{d}{\rho_1} + \log_h \frac{d}{b}$$

$$\frac{\text{abhenrys}}{\text{system cm.}} \qquad (34)$$

It may be observed that as the two rails are brought closer together, M_{12} is increased; and, finally, if they be merged together

FIG. G.

Cross-section of track and trolley wire. The distance d should be measured from centre of trolley wire to the centre of either rail.

into a single rail, $M_{12} = L_{10}$, so that the last formula reduces to (31) for the case already found of a trolley wire and one rail. The value of M_{12} can always be computed from (33) with satisfactory practical precision. If, therefore, we measure the linear inductance L_1 of a given length l of the rail for infinite flux radius, we can readily compute the system linear inductance for assigned values of d and b by (33) and (34).

Appendix III indicates the procedure in regard to the geometrical arrangement of the rail circuits for enabling L to be measured. In the presence of skin effect, L_1 becomes reduced to an effective value L_1' abhenrys per rail length l, for infinite flux radius.

APPENDIX III.

THEORY OF CORRECTION FOR MUTUAL INDUCTANCE BETWEEN POTENTIAL LEADS AND RAIL CIRCUIT.

In order to determine the mutual inductance between the rail potential leads and the rectangular loop formed by the rail circuit, it was necessary to solve certain preliminary problems.

First.—A straight wire OO' of any small cross-section lies

FIG. H.

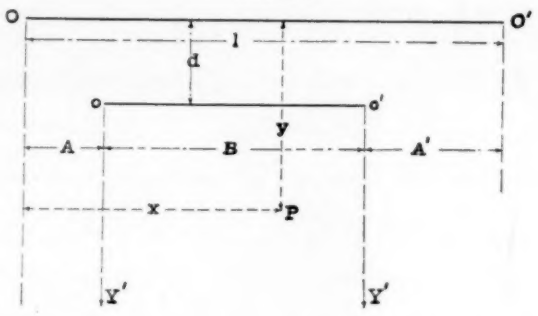


Diagram of geometrical relations between parallel conductors.

parallel to a shorter wire oo', also of small cross-section, the geometrical distances are A, B, A', and d cms. respectively, as shown in Fig. H. Required the mutual inductance between OO' and oo'; *i.e.*, to find the flux emitted by 1 absampère in OO' which enters a rectangle $Yoo'Y'$ containing oo', the sides Y and Y' being indefinitely long. Any point P in the plane of this rectangle has rectangular coördinates x and y.

The field intensity H_P at P due to a current of I absampères in OO' is

$$H_P = \frac{I}{y}\left\{\frac{x}{\sqrt{x^2+y^2}} + \frac{l-x}{\sqrt{(l-x)^2+y^2}}\right\} \quad \frac{*\text{ gilberts}}{\text{cm.}} \qquad (35)$$

* E. B. Rosa, *Bulletin*, vol. 4, No. 2, Bureau of Standards, 1907, p. 303, formula (1).

and the corresponding flux density in a medium of permeability μ is:

$$B_P = \frac{\mu I}{y}\left\{\frac{x}{\sqrt{x^2+y^2}} + \frac{l-x}{\sqrt{(l-x)^2+y^2}}\right\} \quad \text{gausses} \qquad (36)$$

The total flux ϕ in the rectangle $Yoo'Y'$ will be

$$\phi = \int_A^{l-A'} \int_d^{\infty} B_P . dy . dx \quad \text{maxwells} \qquad (37)$$

Taking one integration at a time,

$$\frac{d\phi}{dy} = \int_A^{l-A'} B_P . dx = \int_A^{l-A'} \frac{\mu I}{y}\left\{\frac{x}{\sqrt{x^2+y^2}} + \frac{l-x}{\sqrt{(l-x)^2+y^2}}\right\} dx \quad \frac{\text{maxwells}}{\text{cm. along } Y} \qquad (38)$$

$$= \frac{\mu I}{y}\left[\sqrt{x^2+y^2} - \sqrt{(l-x)^2+y^2}\right]_A^{l-A'} \quad \frac{\text{maxwells}}{\text{cm. along } Y} \qquad (39)$$

$$= \frac{\mu I}{y}\left\{\sqrt{(l-A')^2+y^2} - \sqrt{A^2+y^2} - \sqrt{A'^2+y^2} + \sqrt{(l-A)^2+y^2}\right\} \quad \frac{\text{maxwells}}{\text{cm. along } Y} \qquad (40)$$

and

$$\phi = \mu I \int_d^{\infty} \left\{\frac{\sqrt{(l-A')^2+y^2}}{y} + \frac{\sqrt{(l-A)^2+y^2}}{y} - \frac{\sqrt{A'^2+y^2}}{y} - \frac{\sqrt{A^2+y^2}}{y}\right\} dy \quad \text{maxwells} \qquad (41)$$

Observing that

$$\int \frac{\sqrt{c^2+y^2}}{y}\, dy = \sqrt{c^2+y^2} - c \log_h \frac{c+\sqrt{c^2+y^2}}{y} \qquad (42)$$

c being any constant,

$$\phi = \mu I\Big[\sqrt{(l-A')^2+y^2} - (l-A') \log_h \frac{(l-A') + \sqrt{(l-A')^2+y^2}}{y} + \sqrt{(l-A)^2+y^2} - (l-A) \log_h \frac{(l-A)+\sqrt{(l-A)^2+y^2}}{y} - \sqrt{A'^2+y^2} + A' \log_h \frac{A'+\sqrt{A'^2+y^2}}{y} - \sqrt{A^2+y^2} + A \log_h \frac{A+\sqrt{A^2+y^2}}{y}\Big]_d^{\infty} \quad \text{maxwells} \qquad (43)$$

All of the terms sum to zero at the upper limit (∞) so that

$$-\phi = \mu I \Big\{ \sqrt{(l-A')^2+d^2} - (l-A') \log_h \frac{(l-A')+\sqrt{(l-A')^2+d^2}}{d} + \sqrt{(l-A)^2+d^2} - (l-A) \log_h \frac{(l-A)+\sqrt{(l-A)^2+d^2}}{d} - \sqrt{A'^2+d^2} + A' \log_h \frac{A'+\sqrt{A'^2+d^2}}{d} - \sqrt{A^2+d^2} + A \log_h \frac{A+\sqrt{A^2+d^2}}{d} \Big\} \quad \text{maxwells} \quad (44)$$

The quantity within the final brackets taken with opposite sign is, therefore, the required mutual inductance M abhenrys in a medium of unit permeability.

If we take $A' = A$ this becomes

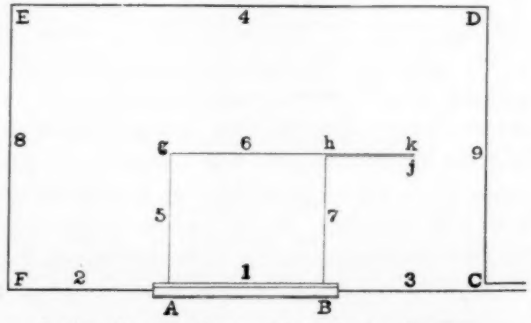
$$-M = 2\Big\{ \sqrt{(l-A)^2+d^2} - (l-A) \log_h \frac{(l-A)+\sqrt{(l-A)^2+d^2}}{d} - \sqrt{A^2+d^2} + A \log_h \frac{A+\sqrt{A^2+d^2}}{d} \Big\} \quad \text{abhenrys} \quad (45)$$

If again $A = A' = 0$,

$$-M = 2\Big\{ \sqrt{l^2+d^2} - d - l \log_h \frac{l+\sqrt{l^2+d^2}}{d} \Big\} \quad \text{abhenrys} \quad (46)$$

which agrees with formula (98) of Rosa and Grover's "Formulæ for Mutual- and Self-Inductance." *

FIG. K.



System of main and potential circuits in rail tests.

In the system of circuits indicated in Fig. K the working circuit is the rectangle $FABCDE$ and the potential-lead circuit is the inner rectangle nearly in the same plane $ABhgA$. It is required to deter-

* *Bulletin*, vol. 8, No. 1, Bureau of Standards, 1912, p. 151. See also Bibliography 35.

mine by computation the electromotive force induced by each element of the work circuit on the potential circuit, and to find the algebraic sum of the same. The vector subtraction of this sum from the voltage measured at the terminals *jk* is the vector *IZ* voltage drop in the rail between the potential points *AB*.

$$E_{jk} = I\left\{(R_1' + jL_1'\omega) + j\omega\,(M_{1\cdot4} - M_{4\cdot6} + M_{231\cdot6} - 2M_{2\cdot1} - M_{8\cdot5} + M_{8\cdot} + M_{9\cdot5} - M_{9\cdot7})\right\} = I\left\{(R_1' + jL_1'\omega) + j\omega M_0\right\} \quad \text{abvolts}\angle \quad (47)$$

Owing to the symmetry of the rectangles, $M_{8\cdot5} = M_{9\cdot7}$ and $M_{8\cdot7} = M_{9\cdot5}$.

$$\begin{aligned} M_0 &= M_{1\cdot4} - M_{4\cdot6} + M_{231\cdot6} - 2M_{2\cdot1} + 2M_{9\cdot5} - 2M_{8\cdot5} \\ &= 2576 - 3738 + 3697 - 2468 + 256 \quad - 510 \\ &= 6529 - 6716 = -187 \quad \text{abhenrys} \quad (48) \end{aligned}$$

$$\text{so that } R_1' + j\omega\,(L_1' - 187) = R_1 + jL_1''\omega = \frac{E_{jk}}{I} \quad \text{absohms}\angle \quad (49)$$

$$\text{and } L_1' = L_1'' + 187 \quad \text{abhenrys} \quad (50)$$

In the above computation the term $M_{2\cdot1}$ and its counterpart $M_{3\cdot1}$ are obtained from the end-effect formula (102) of Rosa and Grover in the publication above referred to.

APPENDIX IV.

OUTLINE OF THE THEORY OF SKIN EFFECT IN STEEL RAILS.

The working theory of the extra effective resistance in steel rails due to skin effect, or the imperfect penetration of alternating currents, is based on two provisional assumptions:

1. That the surface of a rail may be regarded as of negligible curvature for the degree of precision required; so that the skin-effect formulas applying to flat strips, as first developed by Lord Rayleigh,* may be utilized. At the curves in the contour of the rail it suffices to assume, as a first approximation, that the magnetic flux densities and electric current densities are distributed in layers of corresponding curvature beneath the surface.

2. That the magnetic permeability μ of the substance of the rail may be taken as substantially constant at any one r. m. s. rail current-strength, in spite of the fact that, at different depths below the surface, the magnetic flux density B dwindles to zero and the

* Bibliography No. 1.

permeability μ is subject to a certain range of variation. This means that we may take a certain average effective value of μ, which may correspond to the more complex integrated value of μ at different depths. Since at the frequency of 25 ∞ the flux density must fall to one-half within less than 2 mm. of depth below the surface, the effects of changes in permeability at greater depths than 2 mm. rapidly disappear. This subject has recently been investigated by Lombardi.*

Let $ABCD$ (Fig. L) represent a cross-section of a thick sheet of steel $2X$ cm. in total thickness. Let $abcd$ be a 1-cm. portion

FIG. L.

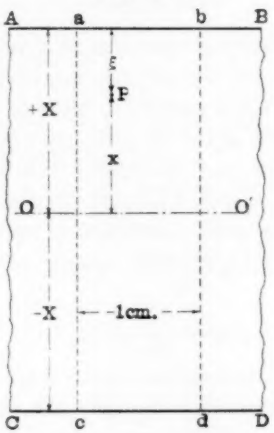


Diagram of cross-section of conducting sheet.

of the section; so that the area of $abcd$ is $2X$ sq. cm. Let the electric current carried in the sheet be directed towards the observer, or be perpendicular to the plane of the paper. Then the magnetic flux in the metal must lie across the current or in the plane of the paper.

At a point P, distant x cm. from the midplane OO' of the sheet, or $\xi = X-x$ cm. below the upper surface AB, let the alternating-current density be i_x r.m.s. absampères per sq. cm. Then we know †

* Bibliography No. 33.

† Bibliography 32, 36.

that in the case of a very wide sheet this current density varies in simple proportion to the cosine of the hyperbolic angle αx where

$$\alpha = \sqrt{j4\pi\gamma\mu\omega} = \sqrt{4\pi\gamma\mu\omega}\,/45^\circ = \sqrt{2\pi\gamma\mu\omega} + j\sqrt{2\pi\gamma\mu\omega} = a_2 + ja_2 \quad cm^{-1} \quad (51)$$

and $j = \sqrt{-1}$, $\pi = 3.14159\ldots$

γ = conductivity of the sheet (abmhos per cm.)
= $1/\rho$ if ρ is the resistivity of the sheet (absohm-cm.)

μ = permeability of the sheet $\frac{\text{gausses}}{\text{gilberts per cm.}}$

ω = angular velocity of alternating current $\frac{\text{radians}}{\text{second}}$

= $2\pi f$, and f is the impressed frequency $\frac{\text{cycles}}{\text{second}}$

Similarly, the flux density B_x gausses at P varies in simple proportion to the sine of the same hyperbolic angle αx, which as shown by (51) is a semi-imaginary quantity, having equal real and imaginary components, each equal to $a_2 x$.

When the sheet has such thickness that with the proper values of γ, μ, and ω the maximum hyperbolic angle αX has a modulus of, say, 6 or more radians, with therefore components of 4.2 or more, it is known that,* owing to the cosine relations of such large hyperbolic angles,

$$i_x = i_X \epsilon^{-a\xi} = i_X \epsilon^{-a_2\xi} \sqrt{\ a_2\xi} \qquad \frac{\text{absampères}}{\text{sq.cm.}} \quad (52)$$

where i_x is the current density at the surface, and ϵ is the Napierian base, so that the current density falls off as we descend into the sheet according to a simple exponential law, at the same time lagging increasingly in phase.

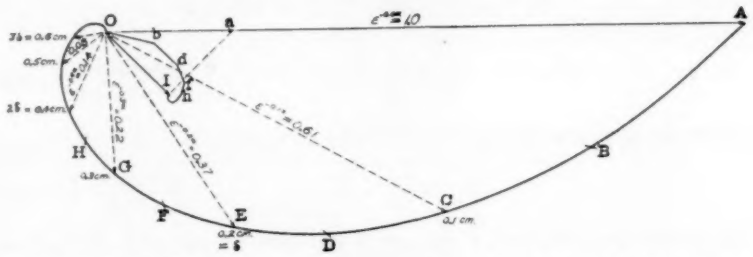
These conditions are indicated graphically in Fig. M. Here the horizontal vector OA, of unit length, represents the alternating-current density at the surface of the strap, in r. m. s. absampères per sq. cm. The diagram is drawn for the particular case where $f = 25\,\omega$ or $\omega = 157.1$ rad/sec., $\mu = 506.6$, $\rho = 20{,}000$ absohms-cm. or $\gamma = 0.5 \times 10^{-4}$ abmho/cm.; so that $a = 7.071\,/45^\circ = 5 + j\,5$ hyperbolic radians per cm. The current density in layers of successive depth will therefore fall off both in magnitude and in phase at the rate $\epsilon^{-7.071\xi}\,/45^\circ = \epsilon^{-5\xi} \sqrt{\ 5\xi}$ radians. If we give to the depth ξ the successive values 0.05, 0.1, 0.15, 0.2 cm., etc., we obtain from this expression the successive vectors OB, OC, OD, OE; and the

* Bibliography 23, 16.

curve *ABCDE* is an equiangular spiral about the origin *O*, the tangent at any point on this curve making an angle of 45° with the radius vector.

It will be observed that at a depth of 3 mm. ($\xi = 0.3$), the current density is 22 per cent. of the density at the surface, and lags nearly 90° with respect thereto. At 6 mm., or 3δ, the current density has fallen to less than 5 per cent., and is nearly in opposite phase to the density at the surface.

FIG. M.



Graph of magnitude and phase of alternating current density at various depths below surface.

The total vector r. m. s. current carried along the sheet per cm. of its breadth may be obtained from the integral

$$I = \int_0^X i \, . \, d\xi = i_X \int_0^X \varepsilon^{-a\xi} \cdot d\xi = \frac{i_X}{a} (1 - \varepsilon^{-aX}) \qquad \frac{\text{absampères}}{\text{cm. breadth}} \angle \quad (53)$$

When, as in the condition assumed, aX exceeds 6, ε^{-aX} is numerically less than 0.015; so that we may take the integral current in the half of the strap above the midplane *OO'*, Fig. L, as

$$I = \frac{i_X}{a} = \frac{i_X}{7.071} \angle -45° = i_X (0.1 - j0.1) \qquad \frac{\text{absampères}}{\text{cm. breadth}} \angle \quad (54)$$

We may also obtain a close geometrical approximation to the total integral current by taking the vector *OB*, the density at the middle of the first 0.1 cm. layer ($\xi = 0.05$). Multiplying this by 0.1, we find the vector current *Ob* in this layer. Next taking the vector *OD* at the middle of the second 0.1 cm. layer ($\xi = 0.15$), and multiplying it by 0.1, we obtain a vector increment *bd*, to be added vectorially to *Ob*, in order to obtain the total vector current in the first two such layers. Proceeding in this way, the total vector r. m. s. current per cm. of breadth of the sheet above the

midplane OO', Fig. L, will be $OI = i_X 0.1414 \angle 45°$ or $i_X (0.1 - j\, 0.1)$ absampères per cm. It is evident that if, as in the case assumed, the current has room to penetrate (αX not less than 6.0, say), the total vector current carried by the sheet will lag just 45° behind the superficially impressed electromotive force and the current at the surface.

If we denote by η_X the electric intensity impressed on the sheet in abvolts per linear cm. acting at the surface, and independent of that consumed in overcoming the external reactance, or producing magnetic flux in the external air, then in each cm. of breadth of the strap we have

$$I = \frac{\eta_X}{Z'} \qquad \frac{\text{absampères}}{\text{breadth cm.}} \angle \qquad (55)$$

and at the surface the current density is

$$i_X = \frac{\eta_X}{\rho} = \eta_X \gamma \qquad \frac{\text{absampères}}{\text{sq. cm.}} \angle \qquad (56)$$

The linear impedance of the strap per cm. of breadth and above the midplane OO' is

$$Z' = \alpha\rho = \alpha_2\rho + j\alpha_2\rho \qquad \frac{\text{absohms}}{\text{breadth cm.}} \angle \qquad (57)$$

The alternating-current resistance R' in the presence of skin effect is then

$$R' = \alpha_2\rho \qquad \frac{\text{absohms}}{\text{breadth cm.}} \qquad (58)$$

But the continuous-current resistance R of the strap per cm. breadth and above the midplane OO' is

$$R = \frac{\rho}{X}. \qquad \frac{\text{absohms}}{\text{breadth cm.}} \qquad (59)$$

The resistance R' would be offered to continuous currents by a certain depth δ cm., such that

$$\frac{\delta}{X} = \frac{R}{R'} = \frac{1}{\alpha_2 X} \qquad \text{numeric} \qquad (60)$$

or

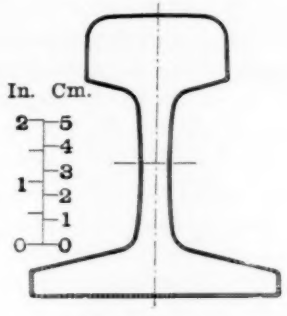
$$\delta = X \cdot \frac{R}{R'} = \frac{X}{\left(\frac{R'}{R}\right)} = \frac{1}{\alpha_2} \qquad \text{cm.} \qquad (61)$$

This equivalent skin depth δ, first arrived at by Rayleigh,* which

* Bibliography 1.

would have the same resistance to continuous currents that the strap above the midplane, offers to alternating currents, is thus equal to the half thickness X divided by the skin-effect resistance-ratio R'/R, and is the reciprocal of a_2. In the case presented in Fig. M, where $a_2 = 5$, the value of δ is $\frac{1}{5} = 0.2$ cm.; that is, 2-mm. skin, on either surface of the plate, would offer the same continuous current resistance. Referring to Fig. M, if we multiply the surface current density OA by $\delta = 0.2$, we obtain a vector current Oa, which leads the total current OI by 45°. The projection of Oa on the vector direction of this total current coincides with OI. A skin depth δ, carrying the r. m. s. current density at the surface, would therefore give a total current, the component of which, in

FIG. N.



Rail No. 174

The shaded superficial layer indicates the effective equivalent skin of depth, $\delta = 0.15$ cm.—as deduced from measurements—at 25.5 ∞ and maximum permeability.

phase with the total sheet current, is equal in magnitude to the latter, assuming plenty of available depth and $aX = 6$ or more. In such cases, the current density at depth δ, attenuates to $1/\epsilon$th and lags 1 radian behind the surface density.

Fig. N represents the cross-section of an ordinary type of steel rail, the effective skin depth δ being 0.15 cm. The actual value of δ in this rail at 25.5 ∞ was found to be 1.55 mm. at μ_{max}. The web of this rail, having a thickness of about 9δ, is fairly well utilized; but the head and the base are only partially utilized for conductance at 25 ∞. The linear resistance of this rail with continuous currents, at, say, 20° C., is supposed to have been ascertained as R absohms per linear cm. The impedance of the rail at the same temperature to currents of a given impressed fre-

quency will depend on the effective permeability μ, which, in turn, depends upon the average magnetic intensity H_X at the surface,

$$H_X = \frac{4\pi I}{P} \qquad \text{r. m. s. gilberts per cm.} \quad (62)$$

where P is the perimeter of the rail section in cm. At any assigned number of r. m. s. ampères in the rail, the average value of H_X will be this number multiplied by $\frac{1.257}{P}$. The linear resistance of the rail at this current strength will be, say, R' absohms per cm. With continuous currents, the whole area of cross-section S sq. cm. will be effective for carrying current, but with the alternating current the effective area S' will be reduced in the ratio $\frac{R}{R'}$, so that,

$$S' = S\frac{R}{R'} \qquad \text{sq. cm.} \quad (63)$$

This effective area S' of alternating-current-carrying capacity is nearly equal to the effective skin depth δ multiplied by the rail perimeter P, or

$$\delta = \frac{S'}{P} = \frac{S}{P}\cdot\frac{R}{R'} = \frac{1}{a_2} \qquad \text{cm.} \quad (64)$$

Consequently

$$\frac{R'}{R} = \frac{S}{P}\cdot a_2 = \frac{S}{P}\sqrt{2\pi\gamma\mu\omega} = \frac{S}{P}\,2\pi\sqrt{\gamma\mu f} \qquad \text{numeric.} \quad (65)$$

Since $R = \rho/S = 1/S\gamma$, it follows that

$$R' = \frac{2\pi}{P}\sqrt{\frac{\mu f}{\gamma}} \qquad \frac{\text{absohms}}{\text{cm.}} \quad (66)$$

or calling $G' = 1/R'$ the linear conductance in the presence of skin effect,

$$G' = \frac{P}{2\pi}\sqrt{\frac{\gamma}{\mu f}} \qquad \text{abmho–cm.} \quad (67)$$

Similarly, if G is the linear conductance of the rail to continuous currents, or in the absence of skin effect; then the skin-effect conductance ratio, or the fraction of utilization of the rail section, is by (64),

$$\frac{G'}{G} = \frac{P}{2\pi S\sqrt{\gamma\mu f}} = \frac{P}{S\sqrt{2\pi\gamma\mu\omega}} = \frac{P}{Sa_2} \qquad \text{numeric} \quad (68)$$

If, therefore, we can find γ and μ for the quality of steel employed in the rail, taking into account the temperature and the value of H_X for the current I, we can compute the skin-effect resistance ratio $\frac{R'}{R}$ at that current. Thus, with $a_2 = 5$, $S = 65$ sq. cm., and

$P = 60$ cm., $\frac{R'}{R} = 5 \times 1.083 = 5.42$. A curve of $\frac{R'}{R}$ may then be plotted for different alternating current strengths carried by the rail, based on the known curve connecting μ and H.

Errors in the Method.

There are two very noticeable sources of error in the above computation; namely, (1) permeability error, (2) shape error.

Permeability Error.—If the permeability μ in formula (65) is taken at the value observed with continuous-current permeameter measurements on a sample bar, for the value of H at the rail surface, corresponding to a given current strength through the rail by (62), it cannot be expected to lead to a correct result for the skin-effect resistance ratio R'/R, since the value of alternating H dwindles at the increasing depths below the rail surface, and the permeability will correspondingly vary. The direction and extent of this error will depend upon the shape of the $\mu - H$ curve for the steel, upon the rate of dwindling as we descend below the surface, and as to whether the maximum value of the permeability is exceeded at the value of H reached on the surface. Since, however, in ordinary steels, the equivalent skin depth δ at electric-railroad frequencies seldom exceeds 2 mm. and the conductance in this skin depth usually greatly preponderates over the sum of all the conductances at depths underlying δ, the errors attributable to this variation in μ at different depths appears by actual measurement to be relatively small, especially in the neighborhood of maximum permeability at the surface.

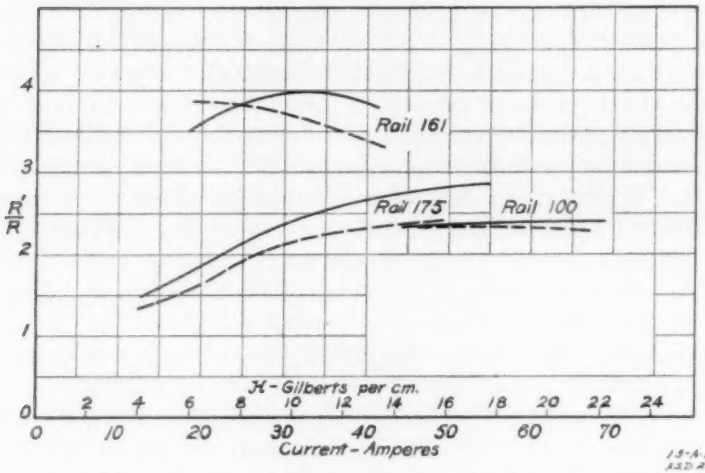
The use of the permeameter value of μ in (65) is also in error, because the ordinary permeameter measures the permeability of the steel sample bar longitudinally, or in the direction of its axis; whereas alternating currents in the rail set up magnetic fluxes near the surface directed cylindrically, and in planes transverse to the axis. Strictly speaking, the transverse permeability and not the longitudinal permeability should be used. It has been found by Miller * that in the case of steel wires and rods there were in some cases appreciable differences between the longitudinal and transverse permeabilities. However, the error attributable to the differences reported seems to be small by comparison with the outstanding errors. It should be noted that the resistance ratio

* Bibliography No. 34 (Bureau of Standards).

R'/R depends on the square root of the permeability, and an error of, say, 5 per cent. in μ would involve only about 2 per cent. in R'/R.

Another source of error in formula (65) is due to the fact that with alternating magnetic fluxes in the skin of the rail there will assuredly be power lost in magnetic hysteresis * and this will tend to increase the apparent resistance of the rail considered as a simple steel cylinder. For this reason, the R'/R found by alter-

FIG. P.



Skin effect at 60 ∾ of steel rods cut from rails. Solid curves observed. Dotted curves calculated.

nating-current measurement in a bar of steel tends to be greater than that computed from the frequency resistivity and permeability by (65), even when the correct value of μ is assumed.

Fig. P compares the resistance ratio R'/R of steel cylinders (38 cm. long and 1.25 cm. in diameter) as measured, and as deduced from the longitudinal resistivity and permeability of the same material. The ordinates are R'/R, and the abscissas are H_X in gilberts/cm. In the case of the steel cylinder cut from rail No. 175, the observed resistance ratio exceeded throughout the value computed by formula (65). In the case of the cylinder cut from rail No. 100, the agreement was very close; while in the cylinder cut from rail No. 161, the curves cross at $H_X = 8$. It appears

* Lombardi, Bibliography, No. 33.

FIG. Q.

ron-filing diagram of alternating-current magnetic flux surrounding an active rail.

from these results that the resistance-ratio of cylinders cut from these steel rails agrees fairly well with that deduced from the longitudinal resistivity and permeability of the same rod at the same temperature.

Shape Error.—Since the ordinary steel rail is everywhere so thick by comparison with the equivalent skin-depth δ at 25∞ that the current density has ample room for attenuation according to (52), the only important error to be considered is the departure from the simple cylindrical form. If the rail were externally cylindrical, the magnetic flux at the surface would be conformal to it at every point. In the actual I or T shape, the magnetic flux tends to pass through the surrounding air from one projection to another, as is shown in Fig. Q, where an iron-filings picture was obtained on one side of a rail (No. 161), when an alternating current of 275 ampères r. m. s. at 60∞ was passing along the rail. It will be seen that the magnetic flux cuts across corners, as though from polar projections, and in passing through the surface of the rail generates alternating electromotive forces in the skin. These electromotive forces, if allowed to close their circuits locally, would produce local eddy currents and consume power, tending to increase the apparent linear resistance R' of the rail. Since, however, the electromotive forces are generated symmetrically throughout the entire length of the rail, we may expect that they will markedly increase the current density at the edges of projections in the contour, and so increase the apparent resistance. This is the same effect as was observed in the case of a steel strap, 3.8 cm. wide and 0.64 cm. thick. The skin-effect resistance ratio R'/R for this strap was found to be 46 per cent. greater than was deducible from its longitudinal resistivity and permeability. It may be called the "edge effect," and is essentially the same phenomenon as occurs in a cylinder; *i.e.*, the current leaves the central region, and crowds into the most distant regions of the cross-section.

The magnitude of the edge-effect coefficient in a steel rail is too complex to be attempted by calculation at the present time. It can, however, be determined experimentally for a given rail section and material, provided we assume that the R'/R of the same rail perimeter, in the form of a cylinder, would be the same as that computed from the longitudinal permeability and resistivity by (65). In other words, if we ignore the permeability and hysteresis errors as trivial by comparison with the shape error and edge effect, the observed value of R'/R for a rail, when divided by the computed value of R'/R, gives the edge-effect coefficient.

LIST OF SYMBOLS EMPLOYED.

α_{20}	Temperature coefficient of resistivity for rail; referred to 20° C. (Temperature $^{-1}$.)
$\alpha = \sqrt{4\pi\gamma\mu\omega}\ /45°$	Propagation constant for a flat strip, a positive semi-imaginary (cm.$^{-1}\angle$).
$\alpha_2 = \sqrt{2\pi\gamma\mu\omega}$	Imaginary or real component of a semi-imaginary propagation constant (cm.$^{-1}$).
B	Flux density (gausses $\angle$).
B_s	Flux density in air gap of Sumpner dynamometer due to potential drop in S (gausses $\angle$).
B_P	Flux density at point P of infinite sheet (gausses $\angle$).
B_x	Flux density at distance x from midplane of sheet (gausses $\angle$).
b	Distance between centres of rails (cm.).
$\gamma = 1/\rho$	Electric conductivity of material (abmhos per cm.).
C_1	Condenser in series with moving coil of Sumpner dynamometer.
C_S	Capacitance of condenser C_1 when M is connected across the shunt S (farads).
C_R	Capacitance of condenser C_1 when M is connected across the rail (farads).
δ	Thickness of equivalent skin (cm.).
D_S	Deflection of dynamometer when M is connected across the shunt S (cm.).
D_R	Deflection of dynamometer when M is connected across the rail (cm.).
D_X	Deflection of dynamometer when M is connected across the rail and R_M substituted for C_1 (cm.).
d	Vertical distance between equivalent centre of rail and the trolley wire (cm.).
E_{AB}	Drop of potential in rail (volts $\angle$).
E_{jk}	Voltage as measured at potential leads jk (volts $\angle$).
E_s	Drop of potential in shunt S (volts).
$\epsilon = 2.71828\ldots$	Napierian base.
η	r. m. s. electric intensity impressed on sheet and acting at surface (abvolts per linear cm. $\angle$).
f	Frequency (cycles per second).
G	Linear conductance of a rail in the absence of skin effect (abmhos/cm.).
G'	Linear conductance of a rail in the presence of skin effect (abmhos/cm.).
H	R. m. s. values of magnetic intensity (gilberts per cm. $\angle$).
H_P	R. m. s. values of magnetic intensity at point P (gilberts per cm. $\angle$).
H_X	Average r. m s. magnetic intensity at surface of sheet (gilberts per cm. $\angle$).
I	R. m. s. current in rail (ampères $\angle$) ; strap absamp/cm.

I_{MS} R. m. s. current in moving coil of dynamometer and condenser C, due to potential drop in shunt S (ampères $\angle$).

I_{MC} R. m. s. current in moving coil of dynamometer and condenser C, due to potential drop in rail (ampères $\angle$).

I_{MX} R. m. s. current in moving coil of dynamometer and resistance R_M, due to potential drop in rail (ampères $\angle$).

i_x R. m. s. current density at ξ cm. from surface of sheet (absampères per sq. cm. /).

i_X R. m. s. current density at surface of sheet (absampères per sq. cm. $\angle$).

$j = \sqrt{-1}$.

L' Total inductance of rail in presence of skin effect (henrys).

L_{oe} External linear inductance of wire to infinity (abhenrys per cm.).

L_{oi} Internal linear inductance of wire (abhenrys per cm.).

L_o Total linear inductance, outwards to infinity, of trolley wire (abhenrys per cm.).

L_{1i} Internal linear inductance of rail (abhenrys per cm.).

L_{1e} External linear inductance of rail, outwards to infinity (abhenrys per cm.).

L_1 Total linear inductance of rail, outwards to infinity (abhenrys per cm.).

L_{10} Total linear inductance of rail in presence of trolley return wire (abhenrys per cm.).

L Total linear inductance of loop of trolley and rail (abhenrys per loop cm.).

L'_1 Total inductance of rail in presence of trolley wire and skin effect (abhenrys).

L''_1 Apparent total inductance of rail as measured by dynamometer (abhenrys).

l Length of trolley wire (cm.).

$\log h$ Napierian or hyperbolic logarithm.

M Moving coil of Sumpner dynamometer.

M_{01} Mutual linear inductance of trolley and rail (abhenrys per cm.).

M_{12} Mutual linear inductance of two rails with respect to trolley wire (abhenrys per cm.).

μ Permeability of rail as measured by direct-current methods $\frac{\text{gausses}}{\text{(gilberts per cm.)}}$.

μ_0 Permeability of trolley wire $\frac{\text{gausses}}{\text{gilberts per cm.}}$.

V_{60}, V_{25} Values of resistance ratio R'/R, at 60 $\sim$ and at 25 $\sim$ respectively (numeric).

ξ Distance of point P below surface of sheet (cm.).

P Perimeter of rail (cm.).

$\pi = 3.14159\ldots$

R'_T Effective resistance of rail at T° C. (ohms).

R'_{20}	Effective resistance of rail at 20° C. (ohms).
R'	Effective a. c. resistance of rail as measured (ohms). Also its effective linear $\propto$ c. resistance (absohms cm.).
R	Direct-current resistance of rail (ohms). Also its linear resistance (absohms / cm.).
R'/R	Skin-effect resistance ratio.
R_M	Resistance substituted for C_1 in moving-coil circuit of dynamometer.
ρ	Resistivity of sheet or rail (absohms-cm.).
ρ_1	Equivalent radius of rail (cm.).
ρ_0	Radius of trolley wire (cm.).
r. m. s.	Root-mean-square value.
S	Area of rail (sq. cm.).
S'	Effective equivalent area of rail to alternating currents (sq. cm.).
S	Resistance of shunt in rail testing circuit (ohms).
T	Value of temperature (degrees Cent.).
τ_s	Torque due to potential drop in S (dyne perp. cm.).
τ_X	Torque due to potential drop in rail with R_M in circuit (dyne perp. cm.).
τ_R	Torque due to potential drop in rail with C_1 in circuit (dyne perp. cm.).
X	Half-thickness of sheet (cm.).
$\omega = 2\pi f$	Angular velocity of impressed alternating current (radians per second).
Z'	Impedance of sheet per cm. of breadth and above the mid-plane (absohms per breadth cm.).
ab or *abs*	Prefix denoting a C. G. S. magnetic unit.
$\angle$	Indication of a complex or plane-vector unit.

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Hydrogen for Military Purposes. E. D. ARDERY. (*Proceedings of the American Electrochemical Society*, April 27–29, 1916.)—For military purposes, hydrogen finds its most important use in inflating balloons, either captive or free. The ascensional force of any gas equals the weight of air minus the weight of an equal volume of the gas, and depends upon the specific gravity, temperature, and barometric pressure of the atmosphere. Hydrogen has twice the ascensional force of pure coal gas and is universally used for military balloons. It permits the employment of smaller balloons, which facilitates transportation and rapid filling, besides affording the enemy a smaller target.

Probably the first method used in generating the gas consisted in the employment of iron or zinc filings and sulphuric acid. The gas from zinc and sulphuric acid is purer than when iron is used. One hundred pounds of sulphuric acid and about 140 pounds of zinc yield 1000 cubic feet of hydrogen. A balloon with a capacity of 16,000 cubic feet would thus require about two tons of these materials, and it is evident that the problem of handling material in the field, to say nothing of the generating and other necessary apparatus, is a serious one. Many processes have been devised to meet the exacting requirements of campaign operations. Among these may be mentioned the "Hydrogenit" process. This is particularly adapted for use where an abundance of water is not available. Hydrogenit is a mixture of finely powdered ferro-silicon and sodium-calcium oxide. It is a gray, sandy substance which, even in a closed receptacle, burns with a large production of hydrogen. The mixture is ignited by means of a match or a small amount of ignition powder. It comes in sheet-metal containers, and is said to keep indefinitely at normal temperatures. The containers are placed bodily in a water-jacketed producer and fired. Calcium hydride is another substance, known as "Hydrolith," which evolves hydrogen rapidly when dropped into water. The objection to it is its excessive cost. Some of the alleged costs per cubic metre (35 cubic feet) of hydrogen gas, according to the process used, are: Ferro-silicon, 20 cents; hydrogenit, 32 cents; hydrolith, 100 cents; steam and hot iron filings, 3 cents; distillation of crude oil and tar, 3½ cents; water gas, 25 cents; old method of iron and sulphuric acid, 25 cents; calcium hydride, 175 cents; silicon and caustic soda, 210 cents. By electrolysis, 1500 ampères produce 23 cubic feet (0.66 cubic metre) of hydrogen and 11½ cubic feet (0.33 cubic metre) of oxygen per cell per hour.

To follow an army's movements, portable plants are necessary, but it appears to be the practice, when possible, to generate the gas in the more economical stationary plants and distribute the product highly compressed in steel cylinders. The compressed gas has the considerable advantage of being immediately available for use. The objections to it are the danger of explosion and the dead weight to be carried.

ON SOME PROPOSED ELECTRICAL METHODS OF RECORDING GAS FLOW IN CHANNELS AND PIPES BASED ON THE LINEAR HOT-WIRE ANEMOMETER.*

BY

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Section 1. *The Venturi Meter in the Measurement of Gas Flow.*

THE application of the hot-wire method of measuring gas flow proposed by the writer [1] depends primarily on its use in conjunction with a Venturi meter as a standard of reference. The reliability of this meter now seems to be well established from the experiments of Coleman,[2] Thomas,[3] and others: according to these writers, however, no method has as yet been devised for obtaining a graphic record by this means. In addition, the measurement of mass-flow by the Venturi meter requires simultaneous record of density.

In order to obtain a sufficiently great pressure-difference (usually amounting to a few inches of water) to be read accurately on the type of pressure-gauges heretofore employed in engineering practice, it has been customary to make use of a somewhat high degree of constriction in the Venturi tube (ratio of radii generally about ½). In these circumstances it is usual to employ, in the calculation of flow, the somewhat complicated adiabatic formula (due to Saint-Venant):

$$Q = A_2(p_2/p_1)^{1/\gamma}.[2p_1\rho_1/(\gamma - 1)]^{1/2} \quad \frac{[1 - (p_2/p_1)^{(\gamma-1)/\gamma}]^{1/2}}{[1 - (A_2/A_1)^2(p_2/p_1)^{2/\gamma}]^{1/2}} \quad . \quad . \quad (1)$$

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where Q is the flow in grammes per sec., A_1 and A_2 the cross-sectional areas at the upstream section and constriction of the Venturi tube respectively, expressed in cm.^{2}: p_1 and p_2 are the corresponding absolute pressures measured in dynes per cm.^{2} and ρ_1 is the density of the gas at the upstream section expressed in grammes per cm.^{3}, while γ is the ratio of specific heats ($\gamma = 1.40$ for air).

In the case of producer-gas [4] which contains small particles of tar-fog in suspension, tar deposits are liable to occur at the constriction, resulting in a decrease of accuracy in flow measurement.

In the application of this method to be used in conjunction with a recording linear hot-wire anemometer, it is proposed to employ an extremely sensitive Töpler differential manometer [5] for measuring pressure-differences across a Venturi tube of much less constriction than is usually employed. This manometer is easily capable of measuring 1 dyne per cm.^{2} (about 10^{-6} atmospheres), so that the Venturi meter may be designed to give pressure-difference of about 5 mm. water (490 dynes per cm.^{2}) at the maximum flow if readings are desired to an accuracy of about ½ per cent. Among the advantages of this method may be mentioned the following:

1. Owing to the small degree of constriction it is easily verified that the complicated Saint-Venant formula (1) from which the flow is calculated is indistinguishable to an accuracy of one part in a thousand from that calculated from the simple formula for incompressible fluids

$$Q = A_1\sqrt{[2(p_1 - p_2)\rho]/[(A_1/A_2)^2 - 1]} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Q being as before the mass-flow in grammes per second, A_1 the

[4] A type of meter suitable for measuring the flow of producer gas is mentioned by B. F. Haanel and J. Blizard in a report on tests of lignite samples (Summary Report of the Mines Branch of the Department of Mines, Ottawa, 1914, p. 118).

[5] For the original description of this instrument, see a paper by A. Töpler, *Ann. d. Phys.*, **56**, p. 610, 1895: also Müller-Pouillet, "Lehrbuch der Physik," vol. i, p. 462. This instrument has been found extremely satisfactory by the writer in the course of experiments on the flow of air in channels. The principal dimensions of the instrument illustrated in Fig. 3 are: distance between centre lines of hinge and micrometer-screw, 45.1 cm.; length of xylol thread, about 23 cm.; micrometer-screw, ½ mm. thread-divided head gives 100 divisions, capable of subdivision by vernier into tenths.

cross-section in cm.^{2} of the upstream section, A_2 that of the constriction, $(p_1 - p_2)$ the pressure difference measured in dynes/cm.^{2}, and ρ the mean density of the gas in grammes/cm.^{3}

2. Tar-fog is less liable to deposit in a Venturi meter in which the degree of constriction is small; in any case, any such tendency can probably be eliminated by maintaining the walls of the Venturi tube at a temperature of a few degrees above that of the gas flowing through it. It is well known that a surface under these conditions tends to repel small particles held in suspension in the gas.[6]

3. Difficulties due to pulsations in the gas line are probably lessened owing to the diminished "choking effect" at the constriction. Oscillations in the Töpler manometer due to this cause can easily be damped out and average pressures read.

Numerical Example.—Consider a 6-inch main conveying producer-gas at about atmospheric pressure at a rate varying between 4000 cubic feet and 15,000 cubic feet per hour. This corresponds to a flow from 1.11 to 4.16 cubic feet per second and a mean velocity between 5.7 and 21.2 feet per second. A diameter of 4.5 inches at the constriction is easily verified to give a pressure-difference of 5 mm. water at the maximum flow, thus:

$$A_1 = 0.196 \text{ sq. ft.} = 182.0 \text{ cm.}^2 \quad A_1/A_2 = [6/(4.5)]^2$$

Assuming the density of the producer-gas to be 1.07 grammes per litre, formula (1) gives $Q = 5.71/(p_1 - p_2)$, and hence when

$p_1 - p_2 = 5$ mm. water $= 490$ dynes/cm.^{2}, $Q = 126.1$ grammes/sec. $= 15{,}000$ cu. ft. per hr.
" $= 0.36$ mm. " $= 35$ " $Q = 33.8$ " $= 4{,}000$ "

Section 2. *Electrical Recording Meter for Low Velocities.*

When the velocity in a pipe does not exceed 90 feet per second, the simplest method of adapting the writer's system of hot-wire anemometry to the recording of gas flow is to insert an anemometer-wire in the line on the upstream side of the Venturi tube section as shown in Fig. 1*a*. According to the principles developed in the writer's work already mentioned,[7] the wire is to be kept

[6] On this subject see Rayleigh, *Roy. Soc. Proc.*, **34**, pp. 414-418, 1882; "Collected Works," vol. ii, p. 151. A discussion, together with further references, is given in *Nature*, **94**, Feb. 4, 1915, p. 615.

[7] See reference (1), p. 571 and also p. 574.

FIG. 1 *a*.

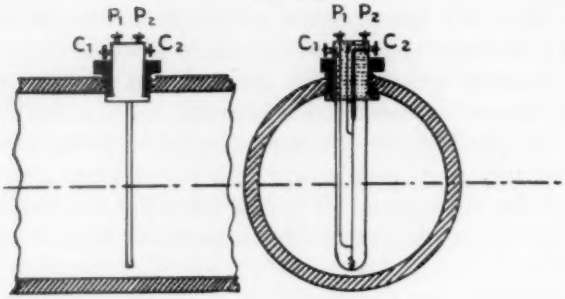
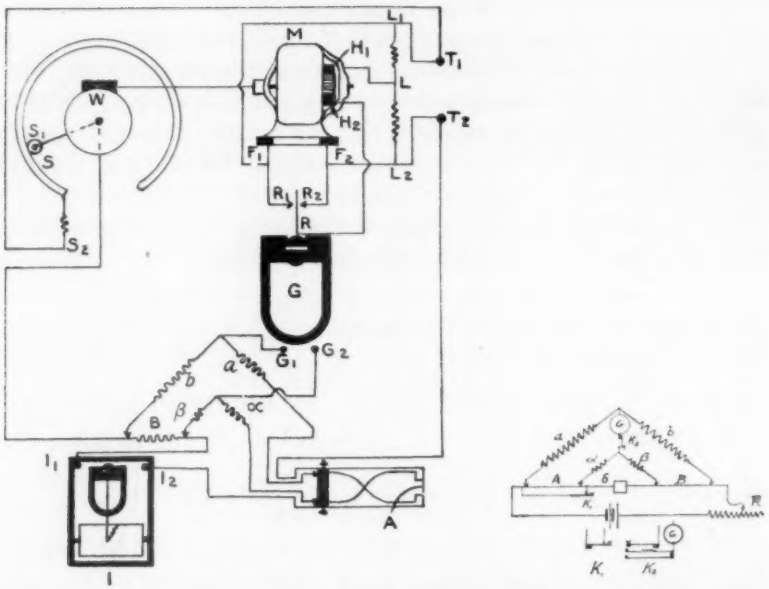


FIG. 1 *b*.



Measurement of Gas Flow in Pipes and Channels by Means of the Recording Linear Hot-wire Anemometer.

Fig. 1 *a* shows an application of the linear hot-wire anemometer adapted to the measurement of flow of gases through large pipes (diameter greater than 3 inches). A brass screw-plug, threaded so as to be capable of insertion in a threaded hole cut into the pipe, carries a central portion of insulating material as shown in the diagram. Fastened to this insulating portion is a stiff framework of narrow, thin steel strip bent in the form of a U, serving both to protect the wire from injury as well as to carry the current to the anemometer-wire from one of the terminals C_1. The other current-terminal C_2 and the potential terminals P_1 and P_2 are disposed as shown in the diagram.

In order to make the readings of flow as given by the recording apparatus Fig. 1 *b** independent of temperature fluctuations in the gas, it is only necessary to construct the ratio-coils *a* and *a* of the Kelvin double bridge of a wire or a combination of wires having the same temperature as the anemometer-wire, and arrange to have these coils exposed to the gas whose flow it is desired to measure.† This may easily be accomplished by inserting in the pipe-line the coils referred to, wound on a framework attached to a screw-plug similar to that already described.

In the larger sizes of pipes a flow-equalizer, consisting of a grid similar to that employed

for the same purpose in the wind-tunnels of aërotechnical laboratories, would probably improve the accuracy and consistency of flow measurement by this means.‡

The type of flow meter just described would have to be calibrated by a comparison with the readings of an absolute meter of the Venturi type. Hence in most applications it would appear preferable to employ the combination of the Venturi meter and the linear hot-wire anemometer as described under Fig. 2.

* For a description of this design of a recording apparatus and its mode of operation see British Patent Specification No. 18,563, 1914, or the writer's paper, "The Linear Hot-Wire Anemometer and its Applications in Technical Physics," JOURNAL OF THE FRANKLIN INSTITUTE, January, 1916.

† On the theory of this mode of temperature compensation see the writer's paper, "Precision Measurement of Air Velocity by Means of the Linear Hot-Wire Anemometer," *Phil Mag.*, 29 April, 1915, pp. 571–572.

‡ The writer is indebted to Dr. R. B. Owens for this suggestion.

automatically at a fixed average temperature of 50° C. to 100° C. above that of the surrounding gas, and the current required to maintain this temperature charted on a recording ammeter. The record must, of course, be calibrated from time to time in terms of the direct Venturi meter and Töpler manometer readings.

According to the theory of the convection of heat from small cylinders developed by the writer,[8] it will be noticed that the energy dissipated as heat from a wire maintained at constant average temperature (and therefore resistance) depends on the product (density × velocity) and on the specific heat, thermal conductivity, and, to a small extent, viscosity of the gas. The specific heat (per unit mass) is known to be independent of pressure and temperature for a gas of constant composition, while the thermal conductivity and viscosity are independent of the pressure and only vary comparatively slowly with temperature over such a range as would probably be met in practice.

Some of the advantages of this method of registration are as follows:

1. The graphical ammeter record obtained in this way can be interpreted as a continuous record of mass-flow or flow in cubic feet per second, measured at standard temperature and pressure. Values of flow so obtained are practically independent of pressure fluctuations in the mains. Any small effect due to temperature fluctuation can easily be compensated for by a suitable design of ratio coils.

2. By integrating this record the total flow during any period can be obtained.

3. The electrical recording apparatus can be installed at any distance from the main, and by a simple commutating device

[8] King, L. V., "On the Convection of Heat from Small Cylinders, etc.," *Phil. Trans. Roy. Soc. Lond.*, vol. 214A, p. 381.

records of flow in several mains may be registered on the same chart.

The difficulties anticipated in the application of this method of measurement to tar-fogged gas such as producer-gas are as follows:

1. Difficulties arising from the varying composition of the gas are inherent in all existing methods of measuring gas-flow. Thomas [9] found, however, from experiments carried out during the development of his electric meter, that the specific heat of illuminating gas remained remarkably constant throughout wide variations in composition. As the interpretation of the records of gas flow by the method just indicated are ultimately controlled by the absolute readings of the Venturi meter, this source of difficulty is easily allowed for if it should be found to exist at all.

2. Tar deposits on the anemometer-wire: as has already been mentioned in Section 1, a heated wire tends to repel small particles suspended in a gas, so that no difficulty is anticipated from this cause. This point is confirmed by the experiments of Thomas in connection with the development of his electric meter.[10] The anemometer-wire is to be maintained at as high a temperature as is consistent with no decomposition of the gaseous constituents.

3. Inspection of the anemometer-wire might necessitate closing down the line: in order to overcome this difficulty it might be necessary to install anemometer-wires in duplicate.

Section 3. *Recording Venturi Meter for High Velocities.*

When the velocities in a pipe greatly exceed 90 feet per second the direct measurement of flow by the hot-wire method is unsuitable, as variations of temperature and resistance become small with increasing velocities. In such cases two small pipes are connected to the upstream and constricted portions of the Venturi tube, and between them is inserted a narrow channel of rectangular cross-section whose dimensions are so adjusted that the pressure-differences due to the range of flow through the Venturi meter will give rise to gas velocities in this "shunt channel" of amounts most suitable for graphical recording by a fine anemometer-wire

[9] Thomas, C. C., "Some Recent Developments in Gas Measuring Apparatus," *Proc. Am. Gas Inst.*, Oct., 1912, pp. 41–42

[10] Thomas, C. C., "The Measurement of Gases," JOURN. FRANKLIN INST., Nov., 1911, pp. 446 and 458. See also reference 9, p. 22.

mounted in the centre of this channel. The main features of this arrangement are shown in Fig. 2 and are there described in further detail.[11] The recording linear hot-wire anemometer thus becomes a device enabling the Venturi meter to be made self-recording. The record thus obtained has the property already mentioned of measuring mass-flow independently of pressure-fluctuations, while any effect due to temperature changes, if existent, can easily be compensated. The records must, of course, be calibrated in terms of the pressure readings of the Töpler gauge placed across the Venturi meter.

This method seems directly applicable to the measurement of compressed-air distribution, flow of *dry* steam, *dust-free* gas at high pressures, etc., under conditions of wide fluctuations of pressure where existing methods of metering are difficult of application. The advantages of electrically recording gas flow already enumerated in the preceding section apply in this case also. More particularly, the connections just described lend themselves more easily to the installation of duplicate "shunt channels" and offer greater facilities for repairs and inspection without interrupting the flow or the recording.

In addition to the difficulties already mentioned in the preceding section with reference to the measurement of the flow of producer-gas, there is the serious danger of the narrow "shunt channel" becoming clogged up. If serious, this difficulty might perhaps be overcome by depositing dust or tar-fog electrically in the upstream pipe of the "shunt channel": this might be accomplished by mounting an insulated wire in this portion of the pipe and maintaining it near "corona" potential by means of a small high-voltage transformer. Experiments describing the successful cleaning of gas from tar-fog by electrical means have recently been published.[12] The deposition of tar-fog might also be prevented by maintaining the "shunt channel" at a temperature of a few degrees above that of the gas. As it is intended that the velocity measuring wire in the "shunt channel" is to be maintained at temperatures from 50° C. to 100° C. above that of the sur-

[11] An arrangement involving the use of a "shunt channel" adapted to a Venturi tube for the measurement of the flow of liquids has recently been described by Dejust, J., *Comptes Rendus*, 161, Oct. 18, 1915, pp. 456–458.

[12] See note on "Tar Removal" in the *Scientific American Supplement*, May 22, 1915, p. 330.

FIG. 2.

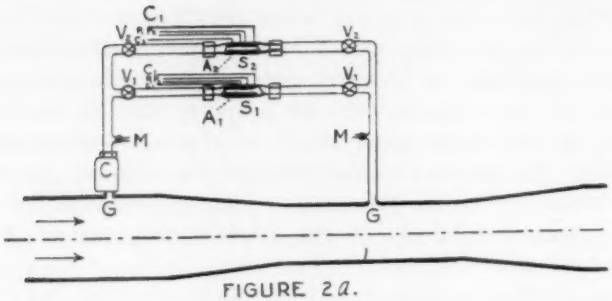


FIGURE 2a.

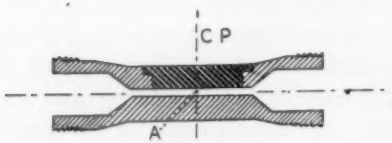


FIGURE 2b.

FIGURE 2d.

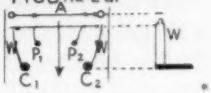


FIGURE 2e

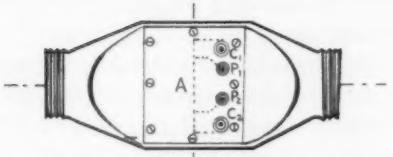


FIGURE 2c.

Electrical Recording Venturi Meter Based on the Recording Linear Hot-wire Anemometer.

Fig. 2 *a* shows a general arrangement whereby a linear hot-wire anemometer mounted in the centre of a narrow "shunt-channel" may be adapted to measure the small pressure-difference across a Venturi tube as described in Section 3. Two such "shunt-channel units," S_1 and S_2, are mounted in parallel, as shown in the figure; one of these is intended to be isolated by means of either pair of stop-cocks V_1 and V_2 and employed either as a spare unit to be operated while the other is being examined or repaired, or it can be reserved to check the readings of the working unit. By means of a sensitive Töpler manometer connected across the stop-cocks MM, the pressure-difference across the Venturi tube may easily be measured in absolute units to 10^{-6} atmospheres. A convenient design suited to the purpose is shown in Fig. 3. From the simple formula (2) applying to a Venturi meter in which the ratio of diameters of cross-sections is maintained as near unity as is consistent with getting an easily measurable flow through the shunt-channel the total rate of flow through the main may be obtained and the readings of the recording ammeter or watt-meter of the recording apparatus calibrated in terms of absolute flow units. In many cases of practical application the varying composition of the gas would require occasional calibrations of the "anemometer" units in absolute measure, so that a Töpler manometer might in these circumstances be included as a permanent part of the apparatus. *C* represents a gas-tight box designed to hold the compensating ratio-coils of the Kelvin double bridge so that they may be exposed to the temperature of the gas being metered, as already explained in the description of Fig. 1. In using this apparatus to measure illuminating gas wire-gauze plugs can easily be inserted in the shunt-channel, as at *GG*, to meet the underwriters' objections to having a heated wire inserted in a pipe directly connected to the mains.

Fig. 2 *b* shows a sectional view of the shunt-channel unit, of which a view from above is shown in Fig. 2 *c*. This unit consists of two main portions, one of which is designed to be inserted into the shunt-line by means of standard couplings. Fitting tightly into this piece, as indicated in Figs. 2 *b* and 2 *d*, is the "anemometer unit," constructed of an insulating material, such as moulded baeklite. Mounted in position so as to lie along the centre of the "shunt-channel," at right angles to the direction of flow, is the anemometer-wire *A*, connected permanently to the current- and potential-terminals C_1C_2 and P_1P_2 respectively.

Fig. 2 *e* shows the method of mounting the anemometer-wire *A* in the shunt-channel.

WW are two springs connected to the terminals C_1C_2. The other extremities terminate in the form of small platinum buttons over which the loops at the ends of the standard anemometer-wires may easily be slipped. The potential leads, permanently fused in position to the anemometer-wire, are connected to the terminals P_1P_2. This mounting is so disposed that the supporting springs are on the down-stream side of the anemometer-wire.

The most suitable temperature at which the anemometer-wire is to be maintained will depend largely on conditions of service and on the nature of the gas which it is desired to measure. In general the temperature should be as high as is consistent with the wire (supposed to be of platinum), not attaining to a temperature of, say, 600° C. in the event of the flow in the shunt-channel being suddenly cut off and the relay-galvanometer (*G*, Fig. 1 *a*) failing to respond instantaneously to this change of flow.

In its application to the measurement of steam-flow, the shunt-channel unit and Töpler manometer would have to be designed to withstand the necessary pressure: difficulties liable to arise from the "wetness" of the steam might be eliminated by superheating that part of the steam-flow passing through the shunt-channel.

It is hardly necessary to remark that the linear anemometer and recording mechanism may be constructed to operate with alternating as well as with direct current. It may also be noticed that the automatic adjustment of the anemometer-wire to constant temperature above the surrounding gas is unaffected by fluctuations of line-voltage. Hence the recording Venturi meter based on the linear anemometer may be operated from the ordinary direct-current or alternating-current lighting circuit independently of the voltage regulation.

rounding gas, no difficulty is anticipated from deposits being made on the wire itself.

On account of the difficulty just mentioned the method described in Section 2 is to be employed whenever possible in measuring gas flow under conditions involving danger from tar deposits.

In the case of clear gases, however, the writer is disposed to recommend the shunt method in all cases as probably being the more accurate and convenient in practice: this arrangement permits the standardization of the shunts and recording mechanism for all ranges of flows, an important point if the recording meter just described is destined to have extensive application in practice.

Section 4. *Mathematical Theory of the Electric Recording Venturi Meter Based on the Linear Hot-Wire Anemometer.*

We will assume the anemometer-wire to be mounted in the shunt channel (see Fig. 2*b*) in which the distance between the walls is $2b$ and the length in the direction of flow l. The dimensions of this channel should be adjusted so that the flow through it under the pressure-difference across the Venturi tube falls within the régime of viscous stream-line flow. If the anemometer-wire be adjusted parallel to the walls of the channel at a distance y from the central plane, the velocity of the gas past the anemometer-wire under the pressure-difference $(p_2 - p_1)$ is given by the equation [13]

$$V = (1/2\mu_0)(b^2 - y^2)\cdot(p_2 - p_1)/l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Combining equations (2) and (3), the rate of mass flow Q through the Venturi tube is given by an expression of the form

$$Q = K_1(\mu_0\rho_0 V)^{1/2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

[13] See Lamb, "Hydrodynamics," 1906, p. 542.

where ρ_o is the density and μ_o the viscosity of the gas referred to its temperature θ_o. K_1 is a constant depending only on the fixed dimensions of the Venturi tube and on the adjustment of the shunt channel, as well as on the position (preferably at the centre) of the anemometer-wire in this channel: in terms of these quantities it is given by the relation

$$K_1 = 2A_1 l^{\frac{1}{2}}[(A_1/A_2)^2 - 1]^{-\frac{1}{2}}(b^2 - y^2)^{-\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Referring now to the writer's theory of the temperature-compensated Kelvin double bridge employed in conjunction with the linear hot-wire anemometer,[14] the current i required to main-

FIG. 3.

A Töpler manometer for measuring minute pressure differences.

tain the wire at constant temperature-difference $(\theta - \theta_o)$ above the temperature θ_o of the surrounding gas is approximately (neglecting radiation from the wire and the variation of the convection constants with the temperature θ_o) given by an equation of the form

$$K_2 i^2 = \gamma_o' + \beta_o' V^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

K_2 is a constant depending only on the resistances (A_o, a_o, B, β) forming part of the Kelvin double bridge, and is given by the relation

$$K_2 = a_o L^{-1}(a_o/A_o - \beta/B)^{-1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where A_o is the resistance at 0° C. of the anemometer-wire whose

[14] King, L. V., "On the Precision Measurement of Air Velocity, etc.," *Phil. Mag.*, **29**, April, 1915, pp. 571–572.

length between potential terminals is L. The resistance a_o (referred to 0° C.) is constructed so as to have the same temperature-coefficient as the anemometer-wire A_o: (B, β) are constructed of manganin and are thus practically unaltered by temperature changes.

β'_o and γ'_o are the convection constants of the anemometer-wire referred to the temperature of the surrounding gas, the accented symbols indicating that temperatures are supposed to be expressed in the "platinum scale." Over moderate ranges of temperature (say about 500° C.) these values differ very little from the corresponding quantities referred to the true scale, whose values, according to the theory developed by the writer,[15] are given in terms of the thermal constants of the gas by the relations

$$\gamma_o = \kappa_o \text{ and } \beta_o = 2(\pi s_o \rho_o \kappa_o a_o)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

κ_o is the thermal conductivity of the gas, s_o its specific heat per unit mass (at constant volume), while a_o is the radius of the anemometer-wire. All these quantities are referred to the temperature θ_o of the gas being measured. From the experiments of the writer on the convection of heat from small platinum wires in air, these theoretical values were satisfactorily confirmed and were found to have small temperature coefficients represented by the equations

$$\gamma = \gamma_o[1 + 0{\cdot}00114(\theta - \theta_o)], \quad \beta = \beta_o[1 + 0{\cdot}00008(\theta - \theta_o)] \quad . \quad . \quad . \quad (9)$$

As experiments in air indicate that the term $\beta V^{\frac{1}{2}}$ of the formula for heat convection is always much greater than the term γ over the range of velocities which it is proposed to measure,[16] we are justified in neglecting the effect of the fluctuations of the gas-temperature θ_o on the accuracy of equation (6). The same experiments indicate that so long as the temperature is not raised beyond 500° C. the heat-loss by radiation is very small compared to the radiation losses.[16]

Identifying (β_o, γ_o) with (β'_o, γ'_o) over the range of temperature, we obtain from equations (6) and (8)

$$(\mu_o \rho_o V)^{\frac{1}{2}} = (K_2 i^2 - \kappa_o)/(4\pi s_o a_o \kappa_o / \mu_o)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

According to the Kinetic Theory of Gases, we have the relation

[15] King, L. V., "On the Convection Constants of Small Platinum Wires, etc.," *Phil. Trans. Roy. Soc.*, 214A, 1914, p. 381.

[16] *Loc. cit.*, Tables V and VI, pp. 420 and 422.

$\kappa_0 = f\mu_0 s_0$, where f is a purely numerical factor independent of temperature and density, a result which has been verified by experiment, at any rate over moderate ranges of temperature.[17]

We may thus write

$$(\mu_0\rho_0 V)^{\frac{1}{2}} = (K_3 i^2 - \kappa_0)/K_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where $K_3 = 2s_0(\pi f a_0)^{\frac{1}{2}}$ is a constant (theoretically) independent of the temperature and density of the gas flowing past the anemometer-wire. It may be noticed here, in view of ultimate practical applications, that Thomas [9] found that the specific heat s_0 of illuminating gas remained remarkably constant throughout wide variations in composition: from an inspection of the available determinations of the factor f as well as from theoretical considerations there is reason to believe that this factor will not vary much with varying composition of the gas measured. The thermal conductivity κ_0, in equation (11), is (theoretically) independent of the density, but has a temperature coefficient of the order 0.002 for air: this term is, however, small compared to $K_2 i^2$, so that the variation of this term with the temperature θ_0 of the gas will not seriously affect the term on the left-hand side of equation (11). We thus obtain from (4) and (11)

$$Q = K_1(K_2 i^2 - \kappa_0)/K_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

which for experimental purposes may be written more conveniently in the form

$$Q = K(i^2 - i_0^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

In this formula we have seen that there is reason to believe that the constant K will be independent of both temperature and density of the gas being measured, and probably, to a great extent, independent of the relative proportions of the constituents in the case of a mixture of hydrocarbons. The constant i^2_0 is (theoretically) independent of the density, but may be expected to vary slightly with temperature. Its value is, however, small compared with i^2 over the working range of the instrument. It should be noticed that i_0 is not the current which would actually be observed if the gas-flow in the Venturi tube were completely cut off, as the current required to maintain the anemometer-wire at its constant temperature above the surrounding gas will in these

[17] See Meyer, "Kinetic Theory of Gases" (English translation by Baynes), 1899, 291–296.

circumstances be governed by free convection. By carrying out a series of absolute determinations of rate of mass flow by means of the Venturi tube and Töpler manometer, the constants K and i^2_o of formula (13) may be determined. A formula of this type can only be expected to give an accurate interpretation of observed results so long as the velocity of flow past the anemometer-wire exceeds a few centimetres per second.

By integrating equation (13) with respect to the time, we notice that the total flow of gas in any interval may be obtained from the readings of an integrating wattmeter. A little consideration will show that it is possible to employ an integrating wattmeter of the Elihu Thomson or Evershed electric motor type in such a way that its readings will be strictly proportional to the integrated mass flow through the Venturi tube. In these instruments the field coils (without iron) carry the main current, while the armature (also without iron) is a fine-wire coil having in series with it a fixed resistance: the two latter are shunted across the ends of the power-absorbing circuit. The armature shaft carries a copper disc which revolves between the poles of a permanent magnet, so that the retarding force due to the eddy currents set up in this disc is proportional to the angular velocity. In the present circumstances we will suppose that in addition to the constant pivot friction we introduce a constant frictional torque easily capable of adjustment. When the armature of the instrument is rotating under steady conditions the torque developed by the current passing through the instrument is, under the present circumstances, proportional to i^2, the voltage terminals being connected across the constant balancing resistance B, Fig. 1b. We may thus write:

$$i^2 = m\,(dN/dt) + n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where N represents the number of revolutions of the armature per second, m is a constant of the instrument, and n refers to the adjustable constant retarding torque. We thus have from (13) and (14) the relation

$$Q = k[m(dN/dt) + n - i_0^2] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

It will be noticed, from this equation, that if we adjust the constant torque so that $n = i_o^2$, that is, so that the armature of the wattmeter just begins or stops rotating for the value of current

i_o (determined by extrapolation)—we have, on integrating (15) over any interval t, the expression

$$\int_o^t Q dt = C(N_t - N_o) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

where C is a constant independent of the temperature and density of the gas being measured. Should the term i^2_o in (15) turn out to have an appreciable temperature-coefficient, it should be possible to arrange for the constant torque which is proportional to n to have the same temperature coefficient.

In any case the disposition of apparatus which we have been considering leads to a very promising means of measuring the integrated mass flow of gas in a pipe in any interval of time in such a way that it is proportional to the reading of an integrating wattmeter. The wattmeter readings may be expected to give a true measure of mass flow independently of pressure (and therefore density) fluctuations in the mains and very nearly (if not absolutely) independently of temperature changes.

MONTREAL, February 15, 1916.

An Electric Arc Furnace for Laboratory Use. O. P. WATTS. (*Metallurgical and Chemical Engineering*, vol. xiv, No. 12, June 15, 1916.)—In view of the many electric steel furnaces of the arc type now in operation, and the numerous descriptions of these available, it would seem a simple matter to construct a satisfactory furnace for melting metals in the laboratory. This, however, is not as easy as it appears, and the description in this paper of a laboratory furnace of 10 pounds capacity, capable of producing the easily controlled and measured high temperatures, practicable only with the electric furnace, should prove of rare interest to those whose investigations lie in the domain of high temperatures.

The furnace is of the tilting type and rectangular in shape, measuring 16½ inches long, 14½ inches wide, and 17½ inches high. The melting-pot, measuring 8¾ x 6 x 7 inches, is constructed of magnesia brick, 2¼ inches thick; the insulating material between the pot and the sheet-iron shell is slaked lime. A slab of electrically fused magnesia is used for the roof. The electrodes are 1½ inches in diameter and are supported by inclined brackets so as to meet at an angle of 90 degrees above the furnace charge. The electrode holders are water-cooled and arranged with a screw feed. The total weight of the furnace is 334 pounds, and, exclusive of refractories, the cost was $50.

THE ELEMENT OF CHANCE IN SANITATION.*

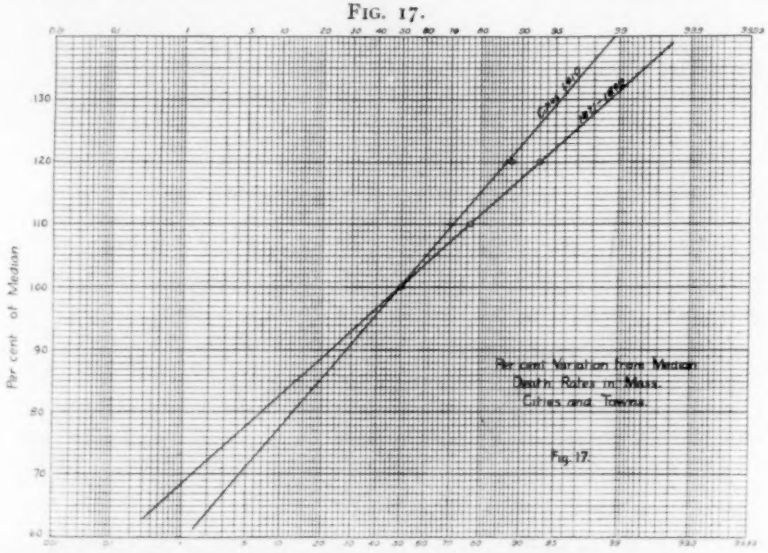
BY

GEORGE C. WHIPPLE, S.B.,

Gordon McKay Professor of Sanitary Engineering in Harvard University.

In studies of vital statistics the attempt is often made to compare death-rates for different years or in different places in the effort to trace the effect of some supposed cause—such, for example, as an improvement in the public water supply or the introduction of a sewerage system or some improved method in public health administration. In making these studies, it is necessary to take into account the fluctuations in the death-rates which are due to many other causes than the ones under investigation. A con-

FIG. 17.



Variations in death-rates plotted on probability paper.

siderable amount of fallacious reading by sanitarians has resulted from failure to take these variations into account. Here the laws of probability will prove useful.

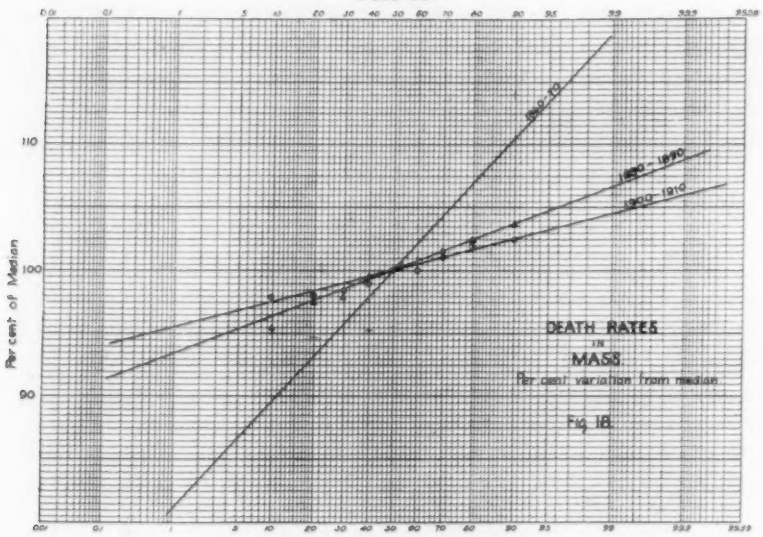
Analyses of Milk.—Fig. 19 shows how the probability paper

* Presented at the meeting of the Mechanical and Engineering Section held Thursday, March 9, 1916.

* Concluded from page 59 of July issue.

may be used in milk analysis. From the records of analyses made by Mr. Lythgoe in the laboratory of the Massachusetts State Department of Health, it was found that, in the case of a long series of samples, the median amount of solid matter was 12.3 per cent. One sample in every ten contained as high as 13.3 per cent. and as low as 11.4 per cent., while one sample in every hundred contained as high as 14.8 per cent. and as low as 10.3 per cent. It will be noticed that that portion of the curve below 11 per cent. did not follow the other section of the curve. This doubtless indicates a special cause acting on 4 per cent. of the samples. This may perhaps be taken to indicate adulteration in the case of this percentage of samples.

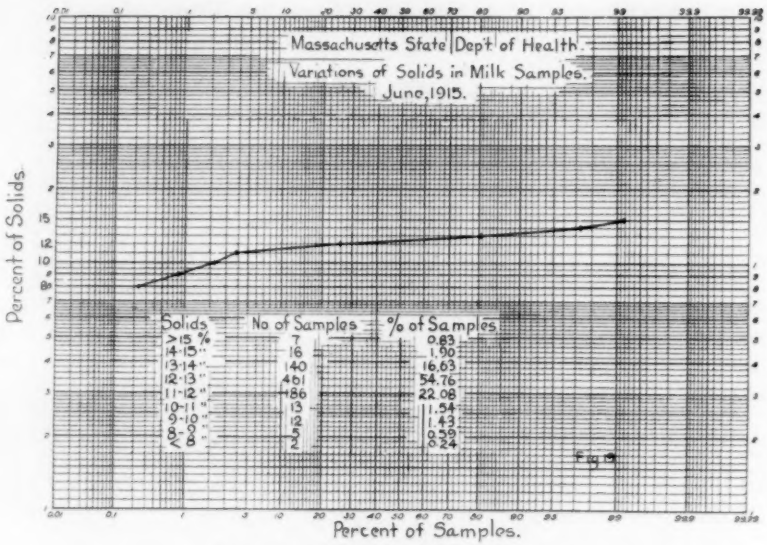
FIG. 18.



Variations in death-rates plotted on probability paper.

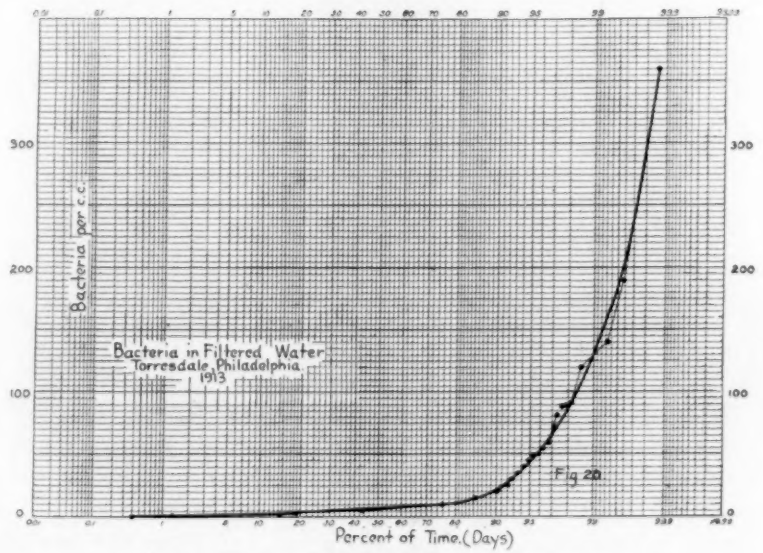
Logarithmic-probability Paper.—In applying the arithmetic-probability paper to certain series of observations, it was found that in some cases the points did not fall upon straight lines, but in curves. An attempt was therefore made to modify the paper by changing the vertical scale. The scheme which proved most successful was to use a logarithmic scale for the ordinates. It was found that, in many cases, points which did not fall in a straight line on the arithmetic-probability paper did fall approximately in a straight line or a gentle curve on the logarithmic-probability paper.

FIG. 19.


Massachusetts State Dep't of Health.
Variations of Solids in Milk Samples.
June, 1915.
Percent of Solids.
Percent of Samples.
Solids | No of Samples | % of Samples
>15 % | 7 | 0.83
14-15 " | 16 | 1.90
13-14 " | 140 | 16.63
12-13 " | 461 | 54.76
11-12 " | 186 | 22.08
10-11 " | 13 | 1.54
9-10 " | 12 | 1.43
8-9 " | 5 | 0.59
<8 " | 2 | 0.24
Fig 19

Milk analysis plotted on probability paper.

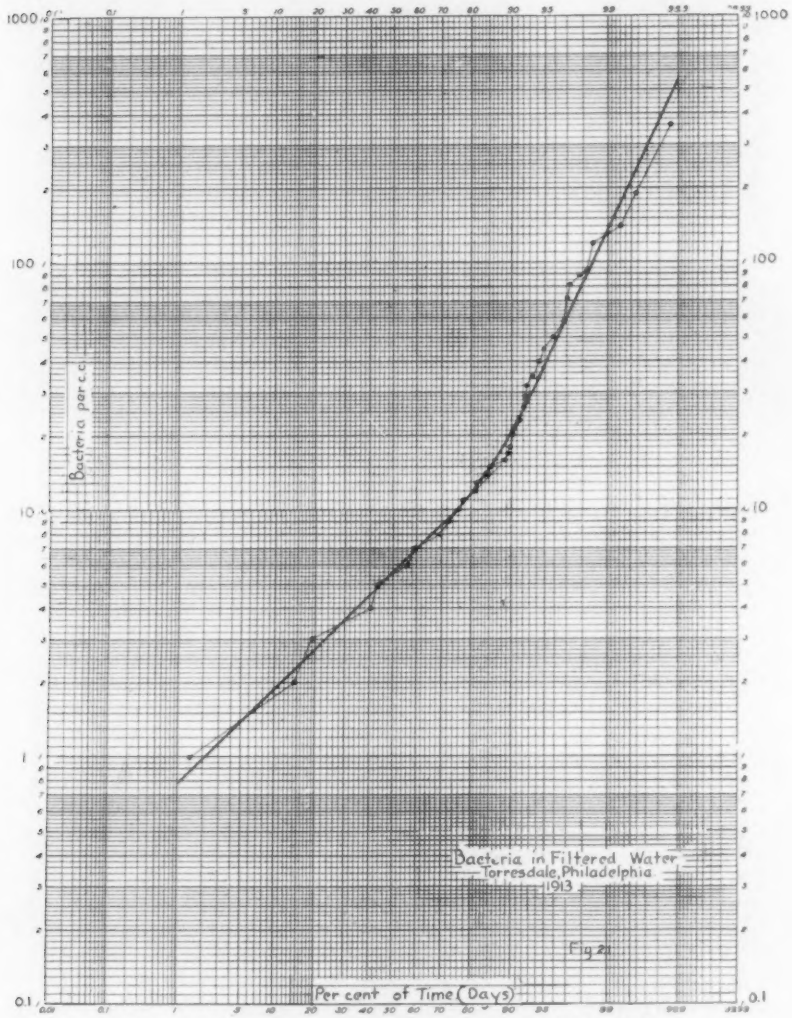
FIG. 20.



Bacteria in filter effluent plotted on arithmetic-probability paper.

An example of this is shown in Fig. 20. Here the number of bacteria in the filtered water from the Torresdale Filter of the Philadelphia water supply was plotted upon arithmetic-probability

FIG. 21.

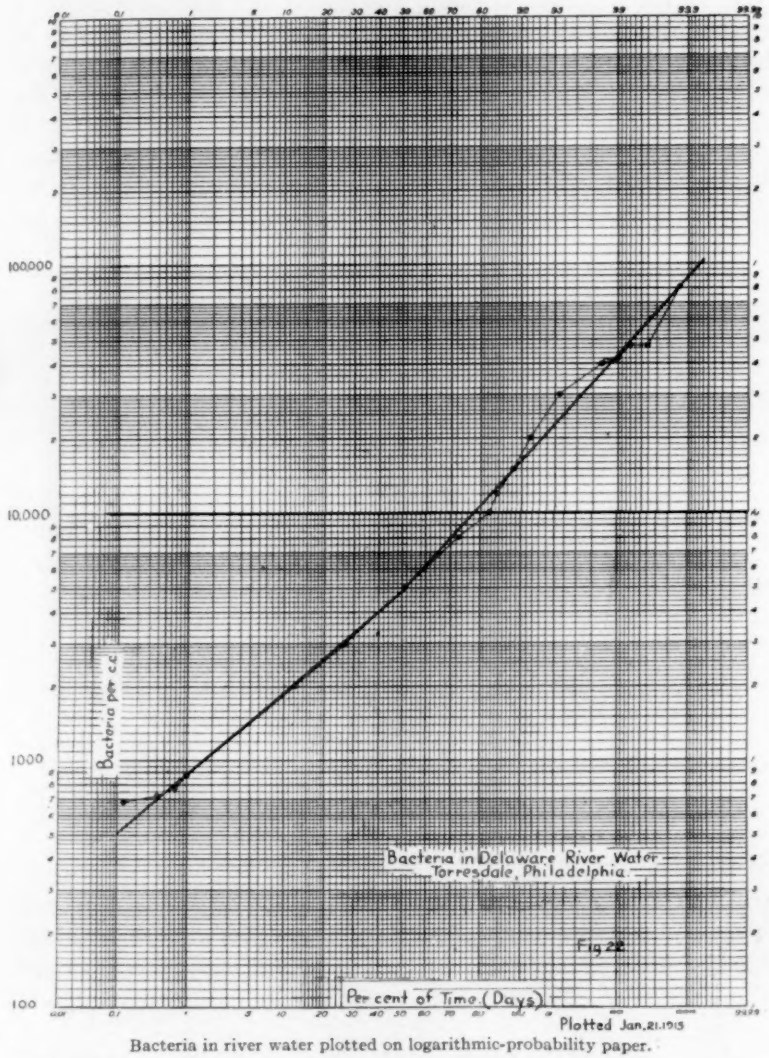


Bacteria in filter effluent plotted on logarithmic-probability paper.

paper, and it will be seen that the points fell along the line of a rather smooth curve. When the same data were plotted on log-

arithmic-probability paper, as shown in Fig. 21, the points fell more nearly on a straight line, but even here the adherence to the

FIG. 22.

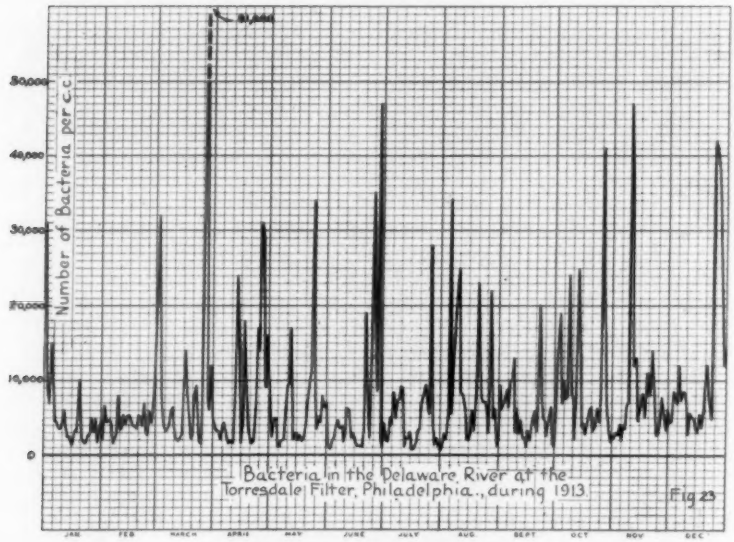


Bacteria in river water plotted on logarithmic-probability paper.

straight line was not exact. The diagram shows, however, that, while the median number of bacteria in a filtered water for the

year was 5.5, the numbers were higher than 100 per cubic centimetre during 1½ per cent. of the time; that is, about 5 days in each year. In the case of the bacteria in the raw water from Delaware River at the Torresdale Filter, the points fell more nearly on a straight line when plotted on logarithmic-probability paper, as shown in Fig. 22. During the year the median number of bacteria in the river water was 4800 per cubic centimetre, but during 10 per cent. of the time the numbers were higher than 16,000 per cubic centimetre, and during 1 per cent. of the time they were higher than 41,500. On the other hand, during 10 per cent. of the time the numbers in the raw water were less than 1900, and during 1 per

FIG. 23.

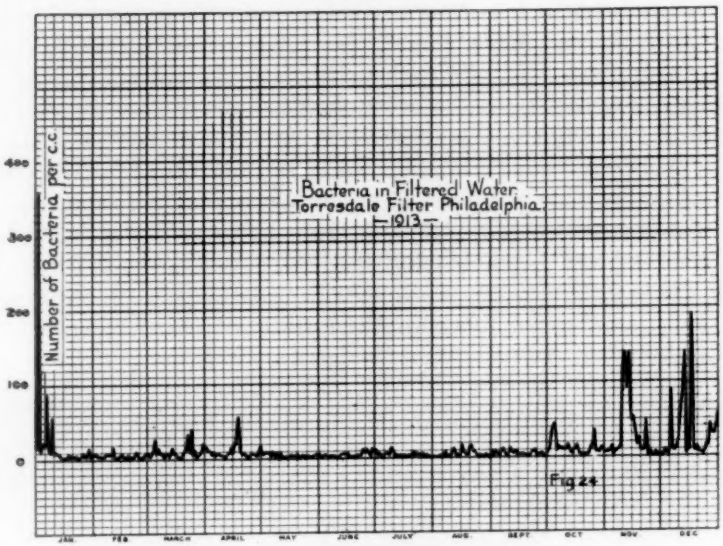


Variations of bacteria in river water.

cent. of the time less than 870. This method of plotting serves to bring out the frequency of certain observations more strikingly than in the case of ordinary plotting in a chronological manner. The ordinary method of showing the results is shown in Figs. 23 and 24.

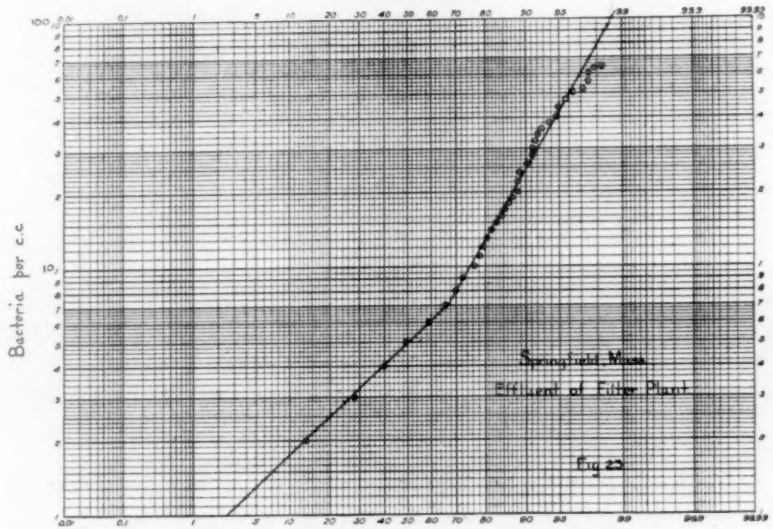
Fig. 25 shows the results of plotting the number of bacteria in the filtered water of the Springfield (Mass.) Filter for the year 1913. In this case the results do not fall exactly on a straight

FIG. 24.



Variations of bacteria in filter effluent.

FIG. 25.

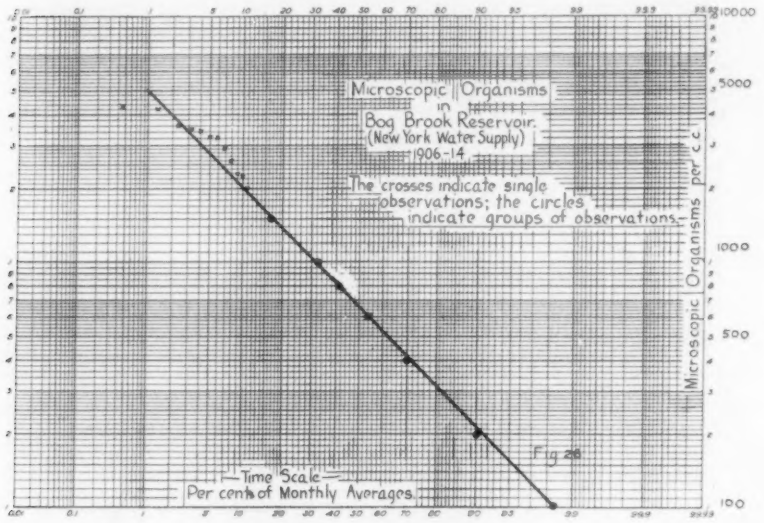


Bacteria in filter effluent plotted on logarithmic-probability paper.

line, but the line drawn shows that the median number in the filtered water was 5 per cubic centimetre; that 10 per cent. of the samples contained more than 25 per cubic centimetre and 1 per cent. more than 200. These results show the filtered water at Springfield to be slightly lower in bacterial content than the filtered water at Torresdale. The difference, however, is not marked.

It has been found also that the algæ and other microscopic organisms in the water of a given reservoir may be plotted as a straight line, or nearly so, on logarithmic-probability paper. This is illustrated in Fig. 26, which shows the microscopic organisms in Bog Brook Reservoir of the New York water supply for the years 1906–1914. During this time the median number of organisms

FIG. 26.



Microscopic organisms plotted on logarithmic-probability paper.

observed was 650 per cubic centimetre, but during 10 per cent. of the time they were higher than 2000, and during 1 per cent. of the time higher than 5000 per cubic centimetre. During 10 per cent. of the time they were lower than 215, and during 1 per cent. of the time lower than 70 c.c.

In order to use the probability paper it is not necessary that the plotted points should fall exactly on a straight line. If the curve is so gentle and uniform that it may be extended somewhat beyond the limits of the plotted points, it will usually be found sufficient.

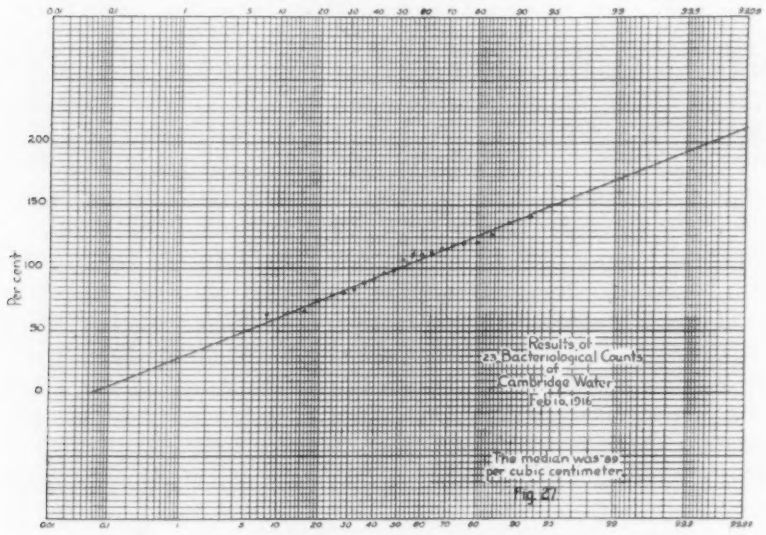
Bacterial Counts in Water.—It is a fact well known to bacteriologists that the quantitative methods of determining the number of bacteria in water, milk, and other liquids are far from accurate. Duplicate determinations seldom agree, and, even when three or more determinations are made with the same samples, there is found to be a very large percentage of error. There are various reasons for this. The ingredients of the culture media are themselves not uniform. The peptone, gelatin, beef-broth, beef-extract, and the like are biological products, and when cooked together the resulting culture medium cannot, in the nature of the case, always be the same. Furthermore, the temperature of incubation, the physical character of the media, the moisture of the air within the Petri dishes are all subject to variations, while differences in the bacteria themselves contribute to the inaccuracy of the result. Liquefiers in gelatin and spreaders in agar play an important part in rendering the results unreliable. In spite of all that the best bacteriologists have been able to do in standardizing methods, it remains true that the precision of the quantitative bacteriological work done to-day is but little in advance of that which was done 25 years ago. Recent attempts to establish standards for waters served by common carriers, for effluents of water filtration plants and sewage treatment works, for shell-fish and other food products are bringing to a crisis some of these matters which relate to the accuracy of quantitative bacteriological results. It is becoming evident that if numerical quantitative standards are to be used and strictly applied it is necessary to have them based upon more accurate methods and more frequent sampling than those now at hand, and that, unless this is done, the numerical standards must be made sufficiently lenient to allow for occasional results which lack in precision. In studying this question the laws of probability may be found useful.

Recently a sample of tap water in Cambridge, Mass., was subjected to repeated bacteriological examination in order to ascertain the precision of the results. The numbers of bacteria were first determined in the usual way on gelatin plates, incubated for 48 hours at 20° C. Twenty-five tests were made, but two of the plates were thrown out because of accidental contamination. The remaining 23 plates were counted and the results studied statistically. The numbers of bacteria varied in the different plates from 57 to 123. The average count was 88 and the median 91. The minimum count was 65 per cent. of the mean, and the maximum

count was 140 per cent. of the mean. When the results were plotted on arithmetic-probability paper, the points fell nearly in a straight line, as shown in Fig. 27. A line drawn through these points indicated that one plate in every ten differed from the median by about 40 per cent., while one plate in every hundred differed from the median by 70 per cent.

Again, 27 plates were made for Cambridge tap water using agar and incubating for 24 hours at 37° C. The mean of these results was 14 bacteria per cubic centimetre, the median 13, the maximum 23, and the minimum 7. In spite of the small numbers, these results, when plotted on probability paper, fell approxi-

FIG. 27.



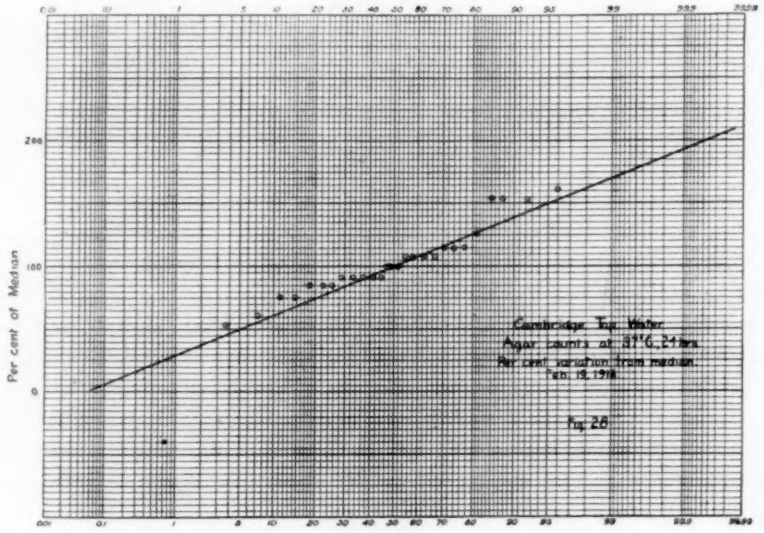
Variations of bacterial counts plotted on probability paper.

mately on a straight line, and, as before, this line showed that one plate in every ten differed from the median by 40 per cent., while one plate in every hundred differed from the median by 70 per cent. (Fig. 28).

These results cannot, of course, be taken to represent the precision of bacteriological counts in all laboratories, made under all conditions. They do, however, illustrate the inaccuracy of the method when applied twice under standard conditions with all possible care.

The bearing which this has on standards of purity is important. Let us assume that a bacteriological standard of 100 bacteria per cubic centimetre has been established, as a permissible limit, and that the precision of the method is that indicated by the line drawn in Fig. 27. If water submitted to this test actually contained 50 bacteria per cubic centimetre, the chance of a single plate count showing less than 100 per cubic centimetre (*i.e.*, 200 per cent. of the actual) would have been 99.96 per cent., and the chance of its showing more than 100 per cubic centimetre would have been 0.04 per cent., or 1 in 2500. If the water contained only 25 bacteria per cubic centimetre, the chance of a single plate showing

FIG. 28.



Variations of bacterial counts plotted on probability paper.

100 would have been vastly less, but the diagram is not extended far enough to determine the chance. If the water contained 75 bacteria per cubic centimetre, the chance of a single plate showing less than 100 per cubic centimetre (*i.e.*, 133 per cent. of actual) would have been 86 per cent., and the chance of a single plate exceeding 100 per cubic centimetre would have been 14 per cent., or about 1 in 7. The following figures show the chance of a single bacteriological count exceeding a given standard of 100 when the

actual number present in the sample is the figure given in the first column:

Number of bacteria present	Chance of a single sample exceeding the standard of 100
100	1 in 2
90	1 in 2.8
80	1 in 5
70	1 in 12.5
60	1 in 66.6
50	1 in 2500

On the other hand, in a sample of water which contained more bacteria than the standard, there would have been a chance that the plate contained fewer bacteria than the standard, and this chance is indicated by the following figures:

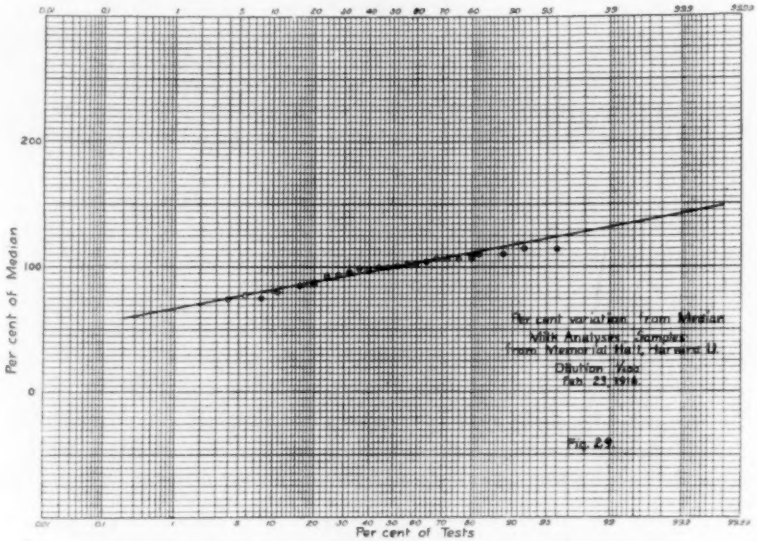
Number of bacteria present	Chance of a single sample being less than the standard of 100
100	1 in 2
110	1 in 2.6
120	1 in 3.4
130	1 in 4.5
140	1 in 6.1
150	1 in 7.7
200	1 in 20

It will be seen from these figures that in the case of waters which contain fewer bacteria than the standard, but near it, the chance of a single count exceeding the standard is high, but in samples which contain much fewer numbers than the standard the chance of a single count exceeding the standard decreases rapidly. In the case of samples which contain more bacteria than the standard the chance of a single count showing less than the standard is considerable. The chance of a bad sample being called good is greater than the chance of a good sample being called bad if the number of bacteria present differs greatly from the standard.

It is evident that when dependence is placed upon a single bacterial count a rigid application of the standard is likely to do injustice either on one side or the other. According to the laws of chance, the probability that two independent events will happen simultaneously is equal to the product of the probabilities of each happening alone. Thus in the case of a water containing 80 bacteria per cubic centimetre the chance of one plate showing more than 100 bacteria is 1 in 5, but the chance of two plates showing more than 100 is 1 in 25, and the chance for three plates giving

more than 100 is 1 in 125, etc. It is evident, therefore, that in order to prevent injustice being done in the application of quantitative bacteriological standards to water it is necessary that several tests should be made. The number of plates which should be made in any given case has not been definitely determined, but, obviously, a large number of plates should be made whenever there is reason to suspect that the water approaches a given standard in its bacterial content. For waters which are expected to be far below the standard two plates would probably be sufficient, but under many conditions five or even ten plates may be necessary to give results which can be safely depended upon.

FIG. 29.



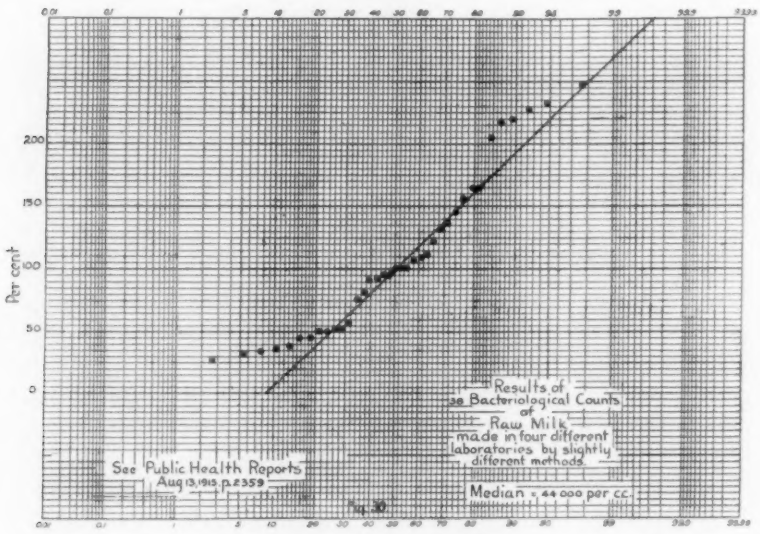
Variations of bacterial counts in milk sample plotted on probability paper.

Bacterial Counts for Milk.—Fig. 29 shows the results of bacteriological examinations of a sample of milk sold in Cambridge, February 24, 1916. Standard methods were used, the culture medium being agar and the dilution 1 to 100. Twenty-five determinations were made. The maximum plate gave 112,000 bacteria per cubic centimetre, the minimum 70,000, the median 94,000. The probability line shown in Fig. 30 indicates that one sample in ten differed from the median by 18 per cent., and one sample in 100 differed from the median by 33 per cent.

It seems obvious that to enforce a strict numerical bacteriological standard for milk or water, based upon methods of analysis, themselves subject to error, is unscientific and, it may be, unfair, unless the regulations also prescribe the frequency of sampling. And one may go further and say that such numerical standards should also take into account the natural variations in the numbers under conditions which may be regarded as safe.

This may temporarily upset the work of certain health departments, but in the end will contribute justice to all concerned. On the basis of these figures it might be said that the bacterial counts

FIG. 30.



Variations of bacterial counts in milk sample plotted on probability paper.

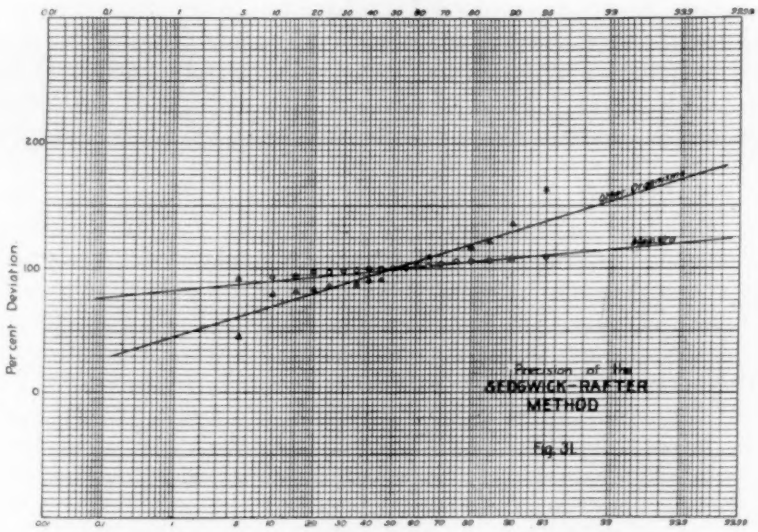
for milk were more precise than for water. It would not do to make this statement, however, on the basis of a single determination made by one person using the same medium under rigid standard conditions. Furthermore, figures given by Professor Conn[4] show a different result. To take one instance: 38 bacteriological examinations of raw milk made in four different laboratories by methods which differed slightly, but all of which are likely to be used, gave results which are shown in Fig. 30. The median of these results was 44,000 per cubic centimetre, the

[4] *Public Health Reports*, August 13, 1915, p. 2359.

minimum 12,000, and the maximum 115,000. These points did not fall as nearly upon a straight line as the preceding. The probability line showed that one plate in every ten was likely to be 90 per cent. above the median result, while one sample in every hundred was likely to exceed the median by 140 per cent.

It is quite evident from these two probability lines that there is much yet to be learned in regard to the precision of bacterial counts in milk. It is evident, however, that the results lack in precision, and this is a factor which must have an important bearing on the application of bacterial standards of purity to milk.

FIG. 31.



Variations in counts of microscopic organisms plotted on probability paper.

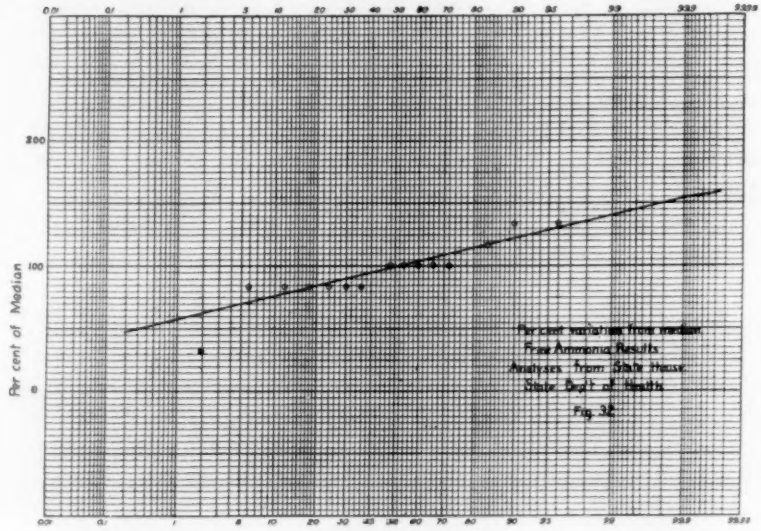
Precision of Sedgwick-Rafter Method.—The precision of determinations of microscopic organisms in water is illustrated by Fig. 31, which shows the result of examinations made for a sample of Cambridge tap water, February 19, 1916, by Mr. Wells of the Water and Sewage Laboratories of Massachusetts State Department of Health. Two lines are drawn, one for Melosira, which happened to be present in large quantities, and one for Miscellaneous Organisms, which include Asterionella, Cyclotella, Cœlospærium, Protococcus, Chlamydomonas, Glenodinium, Peridium,

Tintinnus, and Trachelomonas. The median number of these Miscellaneous Organisms was 100 per cubic centimetre, while the median number of Melosira was 4907 per cubic centimetre. It will be noticed that the determinations for the Melosira were quite precise. One determination in every ten differed from the median by only 7 per cent., and one determination in 100 by 15 per cent., whereas in the case of Miscellaneous Organisms few in number one determination in ten differed from the median by 30 per cent., and one determination in 100 differed from the median by 103 per cent. When these figures are compared with the results of the bacteriological counts, it is seen that the method is more precise when large numbers of organisms are present. The figures given, however, are merely illustrative and are not to be taken as representing the precision of the method under all conditions. When the green algæ are present the precision is probably much less, because it is necesary to estimate their volume in terms of the standard unit, whereas in the case mentioned above the actual numbers were counted.

Precision of Determinations of Free and Albuminoid Ammonia and Oxygen Consumed.—In order to ascertain the precision of chemical determinations of free and albuminoid ammonia and of oxygen consumed, as used in the analysis of water, Mr. Fred. B. Forbes, assistant chemist of the Massachusetts State Department of Health, recently made 16 duplicate analyses of a sample of Boston tap water, collected February 14, 1916. In the case of the free ammonia, the mean of the 16 analyses was 0.012 part per million and the maximum deviation from the mean was 0.004. The results, when plotted on probability paper, indicated that one sample in every ten exceeded the median by 22 per cent. and one sample in every 100 by 40 per cent. In the case of albuminoid ammonia, the mean was 0.118 part per million and the maximum deviation from the mean was 0.016. The probability line showed that once in ten times a determination exceeded the median by 8 per cent. and once in 100 times by 15 per cent. In the case of oxygen consumed the mean of the 16 determinations was 3.3 parts per million, and the maximum deviation from the mean 0.3. The probability line showed that once in ten times a determination exceeded the median by 7 per cent. and once in 100 times by 14 per cent (see Figs. 32, 33 and 34).

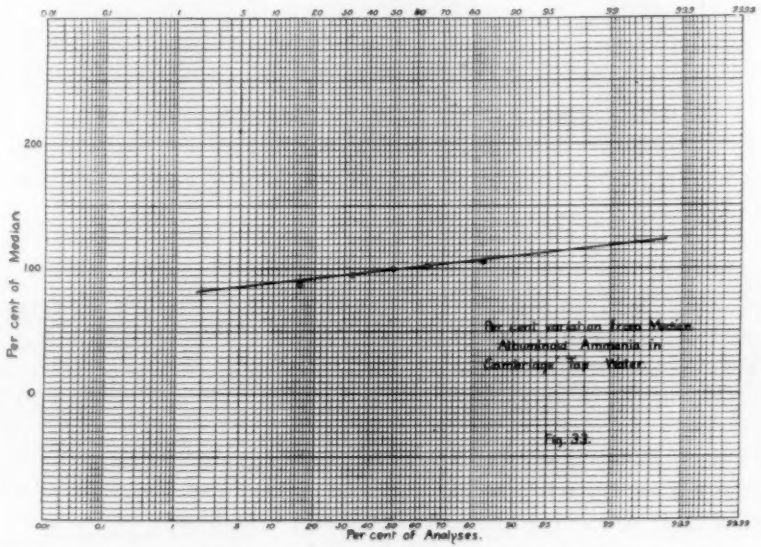
Similar determinations of albuminoid ammonia and free am-

FIG. 32.



Variations in determinations of free ammonia in water plotted on probability paper.

FIG. 33.

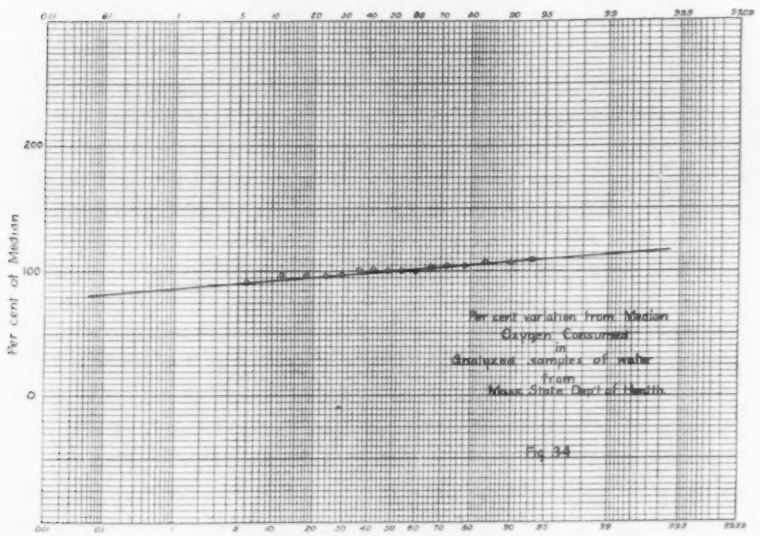


Variations of determinations of albuminoid ammonia in water plotted on probability paper.

monia were made for the Cambridge tap water by Mr. Melville C. Whipple in the Laboratory of Sanitary Engineering, Harvard University. The results were strikingly similar to those which were obtained by Mr. Forbes. When these figures for the chemical analysis of water are compared with those for the bacteriological analysis of water, it is found that the former are far more precise. Greater weight may, therefore, be given to a single chemical analysis than to a single bacteriological examination.

Sand Analysis.—Those who are familiar with sand analysis

FIG. 34.



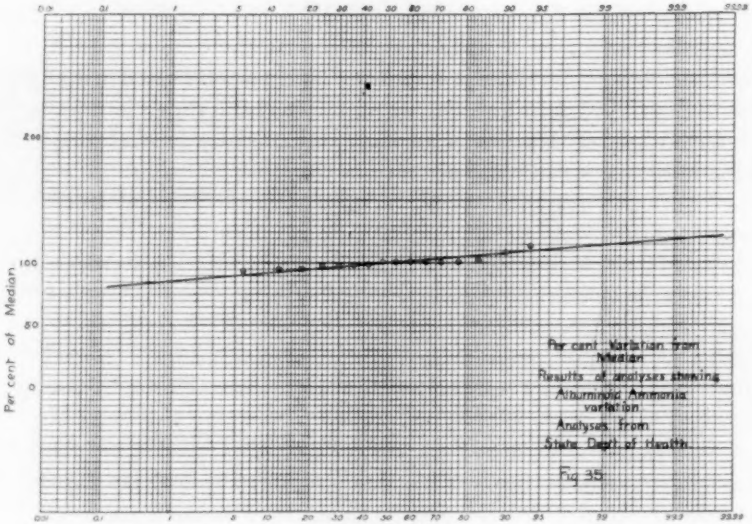
Variations in determinations of oxygen consumed in water plotted on probability paper.

will recognize that the method of sorting sand grains by size and plotting them on sand-analysis paper is substantially a statistical study of the sand grains of different size. On sand-analysis paper the abscissæ are plotted as percentage of weights, while ordinates represent the diameters of the sand grains. The effective size is virtually the lower decentile of the series. The uniformity coefficient of the sand analysis might have been made by comparing the lower decentile with the median, but instead it was made by comparing it with that diameter of grain which was exceeded by 40 per cent. of the weight of the grains. There were good and

sufficient reasons at the time for the adoption of this plan, and it would probably be unwise to change the terminology at this time, as both engineers and contractors are becoming familiar with it. On the other hand, it should be noted that as good a result, and perhaps a better result, might have been obtained by using the theory of probability.

Application of the Probability Curve to Filter Effluents.—For many years it has been customary for sanitary engineers to express the efficiency of filter plants in terms of the percentage of bacteria

FIG. 35.


Per cent of Median
Per cent Variation from Median
Results of analyses showing Albuminoid Ammonia variation
Analyses from State Dept of Health
Fig 35.

Variations in determinations of albuminoid ammonia plotted on probability paper.

removed from the raw water. In the early days of filtration, when interest was focussed upon the mechanism to be employed and the choice of different types of filtration for different kinds of water, this method had much to be said in its favor. It was customary to make tests extending over a limited period of time for the purpose of determining the capability of the filter to satisfactorily purify the water. It was a test of the mechanism.

As time has gone on and the devices employed for filtration have become better known and, to a certain extent, standardized, emphasis has been shifted from the capability of the filter to pro-

duce satisfactory results under conditions of test to the question of sustained operation and the ability of the filter and filter operatives, working together, to produce a water safe and satisfactory at all times. It is being recognized more and more that the old method of expressing the efficiency of a filter plant in terms of percentage removal of bacteria is inadequate, and that some new standard of efficiency is needed which will involve the element of time. It is realized that, within certain limits, slight differences in the percentage removal of bacteria have little or no influence on the real hygienic quality of the water. It is also recognized that with any filter plant there may be a few hours or a few days in the course of the year when the analysis is not satisfactory. This is usually shown by a wide divergence of the analyses from the normal condition. This is sometimes due to errors in the analyses themselves. From the hygienic standpoint the important thing is to determine the frequency and amount of these departures from the conditions of normal operation.

The New England Water Works Association Committee on Standard Methods of Reporting Filter Statistics recognized this need and has taken a step towards it by requiring a statement as to the percentage of time during which the numbers of bacteria in the filtered water were found to be between certain given limits. This, however, is only a step in the right direction, and it is hoped that after the subject has been more thoroughly considered by analysts and engineers some simple method of presenting the facts may be worked out. It seems to the writer that this should be based on the law of probability. This new standard might be somewhat similar in form to the present methods used in sand analysis.

It is too early at present to establish any standard of this kind. This cannot be done until the results for the various filter plants of the country have been collected and studied statistically. My partner, Mr. Francis F. Longley, has made a beginning of such a study, and, speaking generally, the results show that in well-ordered filter plants the median bacterial count for the filtered water is usually less than 20 per cubic centimetre, while during 95 per cent. of the time the bacterial counts are less than 100 per cubic centimetre. Whether 95 per cent. or 90 per cent. or 99 per cent. of the time should be selected as a point for establishing a standard remains to be determined. It would seem, however, that if some figure were established for the median and some other

figure which limited the number during 95 per cent. of the time or less, the combination would give a far better idea of the results of filtration than the old method of using "percentage removal."

Application of Chance to Tests for B. Coli.—Our bacteriological tests of water for *B. coli* are somewhat similar to the drawing of a red ball in one or more trials from a certain number of red balls mixed indiscriminately with a certain number of white balls. Out of a certain number of cubic centimetres of water (the sample) we test one cubic centimetre or some other small quantity to see if it gives certain reactions indicative of the presence of *B. coli*. It either does or it does not; the result is either positive or negative; we have drawn a red ball or a white ball.

Mr. M. H. McCrady,[5] in an excellent article on the interpretation of the results of tests of *B. coli*, has assumed that the laws of probability may be applied in this way, and has deduced some convenient methods of estimating the most probable number of *B. coli* which will produce certain given fermentation-tube results. He says, in substance: "Let us assume that our sample is 100 c.c. and that one cubic centimetre is tested. If one *B. coli* is present in 100 c.c., the chance of its being found in 1 c.c. is one in 100, or 0.01; the chance of its being absent is 99 in 100, or 0.99.

"If there are two *B. coli* in 100 c.c., there are two ways in which the test may be positive; *i.e.*, either one or both may be found in the portion tested, but the reaction will be the same in either case, and we cannot tell whether one or both are present. If the result is negative, however, we know that both are absent. The chance of both being absent is equal to the product of the chances of each being absent, or 0.99×0.99 (*i.e.*, $(0.99)^2 = 0.9801$. The chance of a positive test is, of course, 0.02. If there are three *B. coli* present, the chance of the test being negative is $(0.99)^3$, or 0.9703. The chance of the test being positive is 0.03. And, in general, if the number of *B. coli* present in 100 c.c. is x, the chance of a negative result is $(0.99)^x$ and of a positive result $1-(0.99)^x$. Let us suppose the number of *B. coli* present to be one in each cubic centimetre; *i.e.*, $x = 100$. In this case it might at first be supposed that the chance of a positive result would be 1.0, or certainty. But, not so, because more than one may be present in a single centimetre and perhaps absent from the centimetre tested. From the

[5] "The Numerical Interpretation of Fermentation-tube Results," *Journal of Infectious Diseases*, vol. 17, No. 1, July, 1915, p. 183.

formula $1-(0.99)^x$, when $x = 100$, we find the probability of a positive test to be 0.64; that is, if there were 100 bacteria per 100 c.c. of water, only two-thirds of the 1-c.c. portion tested would give positive results—assuming this method of reasoning to be correct."

Before using his method it is fair to consider carefully as to whether his fundamental assumptions are correct. Is it true that the analogy between the red and white balls and the distribution of *B. coli* in the portions of the sample selected for test is perfect? In the writer's opinion, the cases are not sufficiently similar to enable the laws of chance to be strictly applied. The laws of chance are based on the fundamental idea that the sum of the probability of an event happening and the probability of the event not happening is unity. This is not quite true in *B. coli* tests, for two or more *B. coli* in a single cubic centimetre give the same result, a positive test. Furthermore, bacteria are almost infinitely small as compared with a single cubic centimetre, and there is much more chance that they may be uniformly distributed through the sample and less chance that several would be concentrated in one of the cubic centimetres abstracted from the sample for test than in the case of a mixture of balls, red and white. The so-called anomalies in *B. coli* tests, where a 10-c.c. portion gives a negative result at the same time that a 1-c.c. portion gives a positive result, indicate a certain amount of chance distribution through the volume.

The attempts to interpret the results of *B. coli* tests made by Phelps, Longley, and the Committee of the American Public Health Association on the Examination of Shell-fish, of which the writer was chairman, were based on the concept of a uniform distribution of bacteria through the sample of water. McCrady assumed a distribution such as would occur in a mixture of a few red balls with many white balls. Neither assumption would appear to be entirely correct. An intermediate condition prevails, but at present no one can say which idea is more nearly correct. McCrady's method, however, appears to involve a fallacy which invalidates it, but his work is nevertheless useful in suggesting a stricter use of the laws of probability than has heretofore prevailed. Herein lies a fruitful field for experimental investigation by bacteriologists.

Conclusions.—One might continue to enumerate the applications of the laws of probability almost indefinitely, but perhaps

enough has been said to show that this branch of mathematics can be profitably used by the engineers, chemists, and health officers as well as by the biologists. Oftentimes direct results may be obtained by using the laws of chance, but perhaps the greatest benefit to be derived from the study of probability is the state of mind which it is likely to produce. A realization of the fact that oftentimes many different causes are involved in the production of an event will prevent one from being too sanguine in drawing conclusions from tests, analyses, and statistical data of all sorts, and from being too drastic in the enforcement of standards.

It is believed that in the probability paper which has been described Hazen has given to the profession a new and very useful tool. Heretofore the laws of probability have been used with difficulty; hereafter they may be used with greater facility.

A Cast-steel Wheel with Manganese Tread and Flange. ANON. (*Electric Railway Journal,* vol. xlviii, No. 2, July 8, 1916.)—A one-life, cast-steel wheel with a manganese steel tread and flange and a ductile steel plate around the hub has recently been introduced in the electric railway field by the American Steel Foundries of Chicago, Ill. The product is known as the Davis steel wheel, and its first cost approximates that of a rolled-steel wheel. Its wear life, however, is similar to the wear life of a cast-steel wheel, or even better, because of the tough wheel-tread and flange produced by manufacturing them of manganese steel. The method by which the two kinds of steel are incorporated in one casting was devised especially for the manufacture of the Davis steel wheel. It includes revolving the mould, in which the first metal entering is treated with ferro-manganese during its passage from the ladle into the mould, when the centrifugal action throws it to the wheel-tread and flange. As the pouring continues, the manganese steel rim is gradually blended into a ductile steel plate and hub by tapering off the ferro-manganese treatment.

The advantages claimed for this wheel are that it retains the one-wear principle of the cast-iron wheel and at the same time secures greater strength, safety, and lower maintenance cost. It also avoids the disadvantages of a rolled-steel wheel introduced by turning, which must be followed by adjustments in the bearings and brake rigging whenever the wheels are changed. The extraordinary strength and resistance to wear obtained by the combination of metals in the Davis steel wheel make it possible to produce them in weights lighter than could be obtained in any other metal.

Tractive Resistances to a Motor Delivery Wagon on Different Roads and at Different Speeds. A. E. KENNELLY and O. R. SCHWIG. (*Proceedings of the American Institute of Electrical Engineers,* June 27–30, 1916.)—The object of this research was to determine the resistance offered by level urban roads of different surface varieties to an electric truck at standard truck speeds not exceeding 25 kilometres (15.5 miles) per hour. The truck used in the tests is of the type commonly used for city and suburban parcel-delivery service, having a load capacity of 1000 pounds and a total weight of 1910 kilogrammes (4200 pounds), with a single reduction worm drive. For this purpose the output of the storage battery was measured for both directions of travel over standard road-beds at different controller speeds. From this output were deducted all the corresponding electrical and mechanical losses in the truck mechanism as determined by laboratory tests. The remainder of the output was consequently attributed to (1) road-, (2) air-, and (3) wind-resistance.

With solid rubber tires and speeds varying between 13 and 25 kilometres (8 to 15.5 miles) per hour, the overall efficiency between the battery terminals and the rear-wheel treads reached a maximum value of 78 per cent. under favorable conditions. The mechanical efficiency from the motor to the rear-wheel treads was found to be as high as 90 per cent. The total range of tractive resistance in equivalent grade was from 0.93 per cent. on the best asphalt road, at lowest speed, to 2.7 per cent. on the worst macadam road at nearly the highest speed.

Magnesium. W. M. GROSVENOR. (*Proceedings of the American Electrochemical Society,* April 27–29, 1916.)—Magnesium finds its chief uses as an alloy with other metals and as an intense illuminant of short duration. Alloying itself with aluminum or aluminum containing traces of one or more other metals, it greatly modifies their crystallization and physical properties. It alloys readily with most metals and melts at a convenient heat. As a scavenging alloy, it clears up oxide of other metals, making far denser, cleaner, and stronger and more homogeneous alloys. Because of its intense avidity for both oxygen and nitrogen, it is valuable in aluminum, nickel, copper, brass, etc., and in special steels. In aluminum castings, for instance, less than 2 per cent. of magnesium cleans the metal and leaves ¾ to 1½ per cent. in the casting, about doubling its tensile strength, quadrupling its resistance to shock and jar, and producing a much more easily machined metal. As an illuminant for military uses, it is extensively employed for shrapnel trailers, star bombs, flare-lights, etc., and in photography, for flash-lights. Large quantities are consumed in the manufacture of illuminating bombs and trailers for night firing. For these purposes magnesium produces a result that cannot be approached by antimony or aluminum.

THE FUTURE OF CHEMISTRY IN THE HIGH SCHOOL.*

BY

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1. *The Present State of the Methods of Chemical Instruction.*

THERE is much justification for the current indifference shown by many teachers toward the general theory [1] of the learning process. Educational speculation is an undifferentiated product, in which the valuable contributions of sincere thinkers are mingled with the voluminous nonsense of the lay critic, and with the distorted statements of intellectual acrobats who are trying to struggle into the spotlight by exploiting some phrase which happens to have caught the attention of the multitude. As Professor James remarks—in quite another connection—the result is that we "feel it all as one great blooming, buzzing confusion."

However, contempt for theory is an undesirable attitude on the part of any craftsman or artist, for theory is usually intensely practical. Teaching is a very old profession, and it is most unlikely that ages of occupation with it have produced no valuable deposit. The teaching of chemistry, on the contrary, is a novelty by comparison. Laboratories in the universities date only from the work of Liebig at Giessen; in the high school they are a thing of yesterday. While the teaching of Latin and of the mathematical branches is probably on a reasonably permanent basis so that evolution, but not revolution, may be expected, the methods of teaching chemistry have hardly taken shape at all as yet.

The inchoate condition of methods of chemical teaching—and let me insist that this is wholly natural, and is due simply to the newness of the subject in the schools—is most manifest in the

* Communicated by the Author.

[1] I have elsewhere remarked that this word is used in so many diverse senses that it is desirable either to drop it or to standardize its meaning. In the present paper the word "theory" is used to denote the more abstract portion of a subject; that which is reached rather by reflection than by immediate apprehension.

fact that the text-books still handle the subject by the *analytical* method, a plan which has run through its devastating career in most non-scientific subjects, and which, like the measles and the mumps, is distinctly a disease of childhood. That is to say, the book analyzes the subject into its logical elements. These, for our science, would be electron, atom, molecule, matter, energy, solid, liquid, vapor, phase, crystal, substance, and so on. These are then defined in such a way as to make it possible for the child to pretend that he understands them. If the method was employed in a thorough-going fashion the periodic law, also, as a highly general concept which could "usefully be employed later," would be expounded at the outset. The residue consists in the formal treatment of the subject-matter according to these categories, the familiar applications of which come last in order.

Instead of offering any comment of my own on this inverted procedure, let me intercalate a paragraph from John Dewey, who sums up the matter in a masterly way:

> What is conventionally termed logical (namely, the logical from the standpoint of subject-matter) represents in truth the logic of the trained adult mind. Ability to divide a subject, to define its elements, and to group them into classes according to general principles represents logical capacity at its best point reached *after* thorough training. The mind that habitually exhibits skill in divisions, definitions, generalizations, and systematic recapitulations no longer needs training in logical methods. But it is absurd to suppose that a mind that needs training because it cannot perform these operations can begin where the trained adult mind stops. *The logical from the standpoint of subject-matter represents the goal, the last term of training, not the point of departure.*

As a matter of historical fact, the analytical method gives most unsatisfactory results in practice. Its prevalence is followed by a reaction which goes to the opposite extreme. All logic, all abstract thinking, all generalization are to be excised. The stress is to be laid upon the mental habits and predispositions of the student, and upon his environment outside of school. It is most interesting to note that this reaction against the analytical method in high-school chemistry is just now in full swing. We are to "cut out the theory from the subject," the term "theory" being employed apparently as a convenient inclusive designation for anything which necessitates vigorous reflection. The retort, the beaker, and the balance are to be cast out and "mother's oven," the tea-kettle, and the nutmeg-grater substituted as the new symbols of educational endeavor. Each child, urban or not,

is made to fill a bottle at the kitchen faucet with the home water, to be brought to school and tested with silver nitrate for "sewage," for nothing so abstract as a chlorine ion must be mentioned. It is sometimes objected that, in cities, this is a waste of time, since all the samples would be the same. The objection seems to be very badly founded, for, in the hands of the high-school beginner, the identity of samples is no bar to the most exuberant diversity of results.

This movement is sometimes called the "grease-spot chemistry," on account of the central rôle played by making spots of oil on muslin and taking them out again with gasoline. The humble fruit-spot is less popular, on account of occasional difficulty in removing it, especially from colored fabrics.

I welcome the grease-spot chemistry, and perceive in it elements of great promise. True, many of the subjects taken up are somewhat trivial, and of such a nature that the student's mother could inform him more accurately and expeditiously than can his text-book. True, I should dislike to trust myself, even in a ferry-boat, upon water which had no better sanitary status than the favorable report of a high-school senior. But as an unconscious reaction against a method which introduces generalizations before there is anything to generalize, the movement is a favorable symptom. Progress is usually the net result of just such vibrations, first to one side of the position of equilibrium, then to the other.

That the "new chemistry" is only dimly aware of its own aims and purposes can be gleaned from a study of the books written to guide it, of which there are several now on the market. One would expect them to discard the analytical method, and it is not a little surprising to find them, instead, carrying it to a degree which may fairly be called a *reductio ad absurdum*. The formal logical abstractions of the science are hurled at the student *en bloc* in the first hundred pages, which form a kind of Liebig's Beef Extract of chemical science. Technology occupies the remainder, and the connection between the two portions is of the loosest description.

2. *The Principles Which Form the Basis of the Present Paper.*

But we have run amuck long enough. It is time to become constructive. Let me state, merely because I need them, two maxims which, taken together, make up a thumb-nail pedagogy.

There is nothing novel about them. They are not slogans which originated yesterday and will be forgotten to-morrrow, nor are they bits of euphemistic, alliterative cant. One, at least, was known to the ancients, and very likely the other also—at all events it is equally unquestionable.

(*a*) "Teaching should proceed from the familiar to the unfamiliar, from the easy to the difficult, from the concrete to the abstract." Does the maxim seem unnecessarily wordy? If so, chop it off right behind the ears after "unfamiliar," and you will not mangle the sense seriously. However, the familiar is not always the easy, if the treatment is to be at all exhaustive. The boiling of an egg is familiar enough, yet Emil Fischer, in spite of his marvellous work on the chemistry of the albumins, would refuse to explain exactly what happens.

The last phrase, "from the concrete to the abstract," adds something to the meaning. The concrete is that which is immediately apprehended without effort, and without any chain of reasoning connecting it with anything else. The words "man," "knife," "book" are typical concrete terms. The abstract, on the other hand, is that which is more or less slowly *comprehended* by a train of reflective thought, based on its relation to other things which are more familiar. Atoms, molecules, oxygen, solution are abstract to the beginner, while a term like potassium chlorate is neither concrete nor abstract, but mere jargon, wholly incomprehensible, since by no reflective process can he acquire a conception of its meaning.

Evidently things which are abstract and strange to one person may be concrete and familiar to another, or even to the same person at a later stage in his career. To one who has looked, in the ultra-microscope, at the particles of a colloidal solution being driven hither and thither by the molecular impacts, the conception of molecule becomes concrete. Even the electron acquires a measure of concreteness when it is fired into the ionization chamber of an electroscope, and manifests its presence there by the kick of the projection on the screen. It is plain, also, that the concrete is at first largely the useful—which is sure to be familiar—and that a great part of education consists in the graduated logical conversion of the abstract into the concrete.

And now let us glance at school chemistry in the light of this ancient principle. What are we to think of our introductory

chapter, with its rapid definition of one abstraction after another "to clear the ground?" What of the attempt to explain processes which are themselves abstract, at this stage, by the aid of substances which are not even names to the student, since he cannot pronounce the terms used to designate them, and has not the dimmest glimmering of their meaning? What will it profit the beginner to elucidate the nature of chemical combination to him through the union of aluminum sulphate and potassium sulphate in solution to form hydrous potassium aluminum sulphate? Yet this is an actual instance. What advantage is anticipated from restricting the early part of the work to invisible gases, which the beginner cannot weigh nor handle, and which are themselves abstractions to him? Air is the most familiar gaseous substance, and yet, in the history of human development, it is only the other day, so to speak, that man learned that the air has weight, and it required the intellect of a Galileo to take this forward step.

I can perceive no escape from this dilemma. Either the maxim we have taken for granted is incorrect—in which case education falls into chaos, and there is no such thing as common sense—or else the problem of the most efficient plan of presenting chemistry to the American beginner remains to be solved. We are far ahead of the other nations in the universality of our laboratory work, and in our equipment for it, but far behind some of them in the order of topics and the method of presentation.

It is for this reason that we should extend the hand of fellowship to the devotees of the grease-spot. They are right in their contention that the concrete should play an important part. They are altogether at sea, however, in their desire to occupy the student entirely with the useful, the "practical," with *facts,* in other words, and to banish abstract thinking. Facts which lead nowhere, which are not concerned in any way with generalizations or with the solution of problems, are nearly worthless. Facts cannot be separated from thinking, nor thinking from facts. The jingling stock-phrase "sanitation, not meditation" exemplifies the futility of the attempt, for sanitation without profound meditation is impossible.

(*b*) Knowledge which has been gained with some purpose in view—whether to verify a hypothesis or to carry out successfully some practical operation, seems to make little difference—appears to form an organic part of the mind. It is obstinately retained

and is fairly sure to be instantly available when wanted. On the other hand, information acquired by a mere act of memory is a kind of external mental deposit, for it is relatively evanescent, and it has, moreover, a capricious habit of concealing itself temporarily when most needed.

Let me make a personal confession of a striking instance. For several years I have occupied myself, at different times, with attempting to devise an experiment whereby my students might convert a fixed weight of copper wire into cupric oxide, right in a small porcelain crucible. The idea was attractive, for the change in properties is unmistakable (a most important point in an experiment for beginners), the increase in weight is almost exactly one-fourth of the weight of the copper, and the atomic weight of copper can be neatly calculated directly in terms of the oxygen standard. *Reduced* copper, made by heating the oxide in hydrogen, can easily be oxidized quantitatively in the air, but direct oxidation, even of fine wire, gives an incomplete conversion, and, though the wire can be nicely changed to nitrate in the crucible, the ignition of the nitrate to oxide cannot be effected without loss. Many plans were tried, such as filling the crucible with asbestos fibre, sprinkling the cupric nitrate with oxalic acid, and so on, but none of them worked. Finally, I hit upon the notion of mixing the cupric nitrate, obtained by dissolving a weighed portion of wire in nitric acid, with powdered ammonium carbonate, hoping that the basic cupric carbonate might pass smoothly into cupric oxide on heating. So far as I can recall, it was about the time that the lid of the crucible struck the ceiling that the fact occurred to me that the double nitrate of copper and ammonium had been practically employed in blasting. This bit of information, picked up from Dr. Munro's excellent report on chemical manufactures in the census of 1900, had been in my possession about twelve years at the time, but it was a mere isolated fact, acquired by an effort of memory, kept in cold storage, and quite unavailable when needed. Thus did I relearn it, in connection with a particular problem, and I shall never forget it again.

Was du ererbt von deinen Vätern hast,
Erwirb es um es zu besitzen.
Was man nicht nützt ist eine schwere Last,
Nur was der Augenblick erschafft, das kann er nützen.

This antithesis, between erudition or stored-up learning and wisdom, which is knowledge put to work for the good of its possessor, is of first-rate importance. How can we arrange things in such a way as to cause the largest possible fraction of the learning acquired by the student to take the form of available knowledge, and not of mere erudition in cold—and probably not aseptic—storage?

Let us consider one of the most important of all chemical topics, the study of the atmosphere, which properly belongs in the very early part of the course. According to the analytic plan, which is essentially the current plan, the atmosphere is analyzed by the teacher or the text into its constituents, the properties of ogygen are communicated, then those of nitrogen, then those of the minor components, finally the nature of the air is inferred from its composition. A slightly better order is to make a brief reference to the biological and physiographical importance of the atmosphere at the start, and then to proceed with the dogmatic treatment.

The methodological or inductive way of attacking this subject, which was worked out by the great reformers of chemical teaching, Arendt and Wilbrand, and put into its present form chiefly by Ohmann, starts with the rusting of the metals. It is shown that the rusting is much accelerated by heat, which, however, is not able alone to produce it, since a folded piece of sheet copper, when heated, remains bright on the inside, although the outside becomes badly rusted. The necessity of air can be further brought out by a reference to the tungsten lamps of the laboratory, in which a metal which rusts at once, when heated in the air, is maintained in a vacuum at a dazzling white heat for long periods, without being affected.

The student heats a weighed piece of sheet copper and finds, on reweighing, that there has been an increase. This at once suggests the addition of something from the air. It will be noted that we are following the line of thought which brought about the downfall of Phlogiston and the discovery of oxygen.

Does the air, then, disappear when a metal rusts in it? Iron powder, hanging from a magnet, is burned in a confined volume of air over water. A portion of the air disappears, and the residual gas no longer supports the combustion of a taper.

What about other metals? How much of the air is absorbed

when rusting occurs? A litre of air is passed slowly through a combustion tube containing hot copper, most conveniently by pouring a litre of water into a flask so arranged that the air will be forced over the copper as it is expelled. This is a demonstration experiment, unsuited for laboratory treatment. About eight hundred cubic centimetres of unabsorbed gas collect over water in a graduated cylinder. This gas can now be named, and those of its properties which are not readily accessible can be communicated.

Oxygen, as the gas which disappears in the last two experiments, can also be named at this stage. The fact that it forms a series of compounds with the metals has been exemplified, and the student's knowledge can be enlarged by simple laboratory work dealing with the heating of iron, tin, lead, zinc, and magnesium. The term *oxide* can logically be employed at this time, though many prefer to reserve it until ogygen itself can be prepared. How is this to be accomplished?

Platinum is heated by the student, and silver and gold by the teacher. The lack of action contrasts strongly with the behavior of the base materials, and calls for explanation. The permanence of the lustre of these three metals is recalled, and the connection of this unalterability in the air with their uses pointed out. A little silver oxide is heated by the teacher, and the cause of the inactivity of this class of metals becomes plain. Evidently the oxides of these metals are decomposed by heat, so that, when once obtained, they form a potential source of oxygen.

Mercuric oxide is now introduced, as the oxide of a metal intermediate between the noble and the base metals, and much cheaper than the former. The student heats, in a hard glass tube, a quantity of mercuric oxide so small that it is completely consumed. This apparently trivial point is important, not only for proper economy in the use of such an expensive material, but also on account of the fact that otherwise he will not appreciate that the formation of the gas and the metallic liquid is accompanied by the disappearance of the red powder. This, by the way, forms a good place to call the attention of the students, for the *n*th time, to the fact that their inevitable tendency to take too much of everything is not only wasteful, but that it frequently defeats the whole object of the experiment. Chemical supply houses should put a phonograph on the market which would automatically repeat this

admonition at intervals of five minutes during all laboratory periods.

The student's knowledge of oxygen can now be enlarged with the aid of a cylinder of the compressed gas, the present method of preparing which, from liquid air, can be briefly indicated, to be explained more fully when the liquefaction of gases is discussed.

The potassium chlorate experiment should be deferred. At this time he is without a clue to the mechanism of the production of the gas. The effort to explain the purpose of the manganese dioxide deepens the mystery. Later, the exercise forms a valuable review of combustion, as well as a typical instance of catalysis.

It is, of course, understood that the treatment broadens later to include combustion, flame, the oxides of carbon, and so on. We are now restricting ourselves to the chemical composition of the air. The close of this special topic is formed by a discussion of the work of Priestley, Scheele, Rutherford, Lavoisier, Rayleigh, and Ramsay, in which the parallelism between the path followed by the course and the historical development is clearly brought out. The teacher who is in search of the best method of presenting a topic to beginners may, with great profit, study the history of the subject. It is surprising how often this indicates the best avenue of approach, though there are striking exceptions. The fact that beginners are always much interested in the historical side is also worthy of note.

Preceding this inductive-deductive study of the air, there is, of course, an opportunity for the student to acquire, by simple experimentation, some knowledge of the nature of chemical combination. It would be difficult to devise a worse experiment for this purpose than the one usually recommended—the heating of a mixture of iron filings and sulphur. The change in appearance after heating is slight, the iron sulphide is invariably magnetic, and almost any proportions in the mixture will apparently yield the same result. The usual direction to treat the mass with hydrochloric acid before and after heating adds to the confusion, for the beginner can supply no interpretation of the behavior of his olfactory nerve. Moreover, the hydrogen obtained by treating the unheated substance with acid contains appreciable hydrogen sulphide and has a most unsavory odor. The important features of a chemical process are completely lost in this exercise, which,

as questioning will show, always fails to fulfil its intended purpose.

One brilliant student of the problems of elementary teaching, Karl Scheid, employs calcite for this preliminary work, while another, Otto Ohmann, makes use of some simple experiments on the formation of the sulphides of the metals, especially of copper. The advantages are all with Ohmann's procedure. Scheid's experiments on the heating of calcite to lime, on the slaking of lime, on the dehydration of slaked lime, and so on, suffer from the difficulty that exact results are almost impossible under high-school conditions. Another objectionable feature is that all three of the substances just mentioned are so similar in appearance that, barring accurate quantitative results, the evidence that a change has occurred is indecisive. The primary thing to remember, in planning this introductory work, is that we have no special sense for the recognition of chemical processes. We apprehend them only by the associated physical changes. Scheid forgets this fundamental principle. To let the student convert one white powder into another, indistinguishable from the first, has no effect worth mentioning on the development of his ideas, even if a change in weight is established. Let us be just to Scheid, however, by adding that his course is rich in suggestions of the utmost value, and that no teacher who gives it careful study can fail to derive great benefit.

Ohmann's experiment on the *synthesis of cuprous sulphide* deserves the attentive consideration of the teacher who is in search of a decisive instance of chemical change for his classes. The details are given in my "Laboratory Manual," page 11. The original is in the *Zeitschrift für den physikalischen und chemischen Unterricht,* about five years back. Two of the strong points which it shares with the other similar experiments have been referred to. The results are sufficiently accurate and the change is unmistakable. A third is the fact that the change in weight happens to be almost exactly one-fourth of the weight of the copper—which presents the essence of the matter devoid of all arithmetical complications. A horn-pan hand balance is quite sufficient for the weighing. It is well to clinch matters with a more exact synthesis with No. 30 copper wire and sulphur in a porcelain crucible (*Ibid.*, p. 13).

Let us return to our general principle (*b*). Work of this

kind needs more planning than a course in which everything is communicated, but it is easier in the execution, on account of the whole-hearted participation of the students. Thomas Carlyle remarks somewhere that to sit like a passive bucket, and be pumped into, can, in the long run, be exhilarating to no creature. And, unfortunately, the mental bucket is far more leaky than the physical one.

We can now state the general plan of such a course. Since the leading idea is clearly set forth by Dewey, and since the application to class-room instruction in physics has been worked out by Mann, we can be brief. A problem based on some familiar occurrence is presented. Vagueness is eliminated and the problem defined by preliminary experiments. Thus we find, in our typical case, that other common metals behave like copper, that there is an increase in weight, that the color of the solid formed is non-essential, and that the noble metals are unaffected. A *solution*, a hypothesis suggests itself. This hypothesis involves certain consequences which can be tested by new experiments. *If* the darkening of the copper is *really* due to the action of the air, and not merely to heat, a folded piece of copper will not be affected on the inside, where the air has no access. These tests either quash the hypothesis for good and all, or establish it as a fact which can function as one element of a new problem. True, the air is the cause of the loss of lustre of copper and other metals when heated, but is all or only a part of the air concerned in this? If the latter, air confined over water will only partly disappear when a metal is heated in it. Just how much of the air is taken up by a hot metal? Does the air which remains differ from common air? How does it act towards a burning candle? Is there any similarity between *combustion* and rusting?

This procedure—the sensing of a problem, the limitation and definition of the problem by experiments, the inductive formation of a hypothesis, the deductive treatment of the hypothesis to obtain its consequences, and the testing of the consequences by further experiments—is simply the *scientific method*, the most tremendous weapon in the intellectual armory of mankind. When the mind works in this way it arrives at truth, or, in the absence of sufficient data, at suspended judgment. Other modes of operation show their inherent unsoundness by yielding a chaos of divergent opinions. "By their fruits ye shall know them."

Unfortunately those who understand the method, and are able to use it, form a vanishing minority—hence the deplorable state of the world at the present moment, for when both parties to a controversy employ the scientific method, an irreconcilable difference of opinion is unthinkable. Polemics, based on faulty observations or diverse interpretations, may occur, but shortly the two will either arrive at the same conclusion, or will together admit the impossibility of any valid conclusion and begin once more to accumulate data. A student who had learned the scientific method and nothing else in his four years of high-school life would have spent his time to better advantage and would be better fitted for citizenship than if he had been crammed with subject-matter to the very ears. If he desired to spend his time in that agreeable manner, he could almost at once learn to remove grease-spots much better than the tailor's apprentice, and in five minutes he could find out more about "mother's oven" than the practical gas-fitter will ever know. And, above and beyond all trivial matters, he would possess a talisman far more wonderful and more precious than Aladdin's lamp, which would confer upon him the power to distinguish science from pseudo-science, assertion from proof, truth from falsehood.

No wonder that the historical development so often points out the best order of topics! To teach according to the historical sequence, to give the method of science along with its subject-matter, to throw the work into the form of problems significant to the student, these are little more than statements of the same principle in different words.

3. *Limitations, in Actual Work, of the Two Principles Just Discussed.*

I recall a fellow-student in high school who, during recess, offered a criticism of the teaching of geometry which ran somewhat as follows:

"If these theorems are any good, we ought to learn as many of them as possible in the time we have for the subject. Now we could learn ten times as many if we did not bother with the demonstrations. The demonstrations are useless anyhow, for we are all willing to believe the theorems without proof, and we ought simply to learn them by heart."

The fallacy in the recommendation of this young educational reformer is, of course, that drawing inferences is the main busi-

ness of life, the one thing in which we are all constantly engaged, but his proposal embodies an effective caricature of the present plan of presenting chemistry by trying to nurture the mind of the beginner on an artificial product composed of the results of the science, with little reference to the method by which they are obtained. School geometry is real geometry, as far as it goes, and school Latin real Latin, but school science, conducted on this plan, is not real science at all, but a mere popular survey, from which the essential scientific spirit is absent. This is the main reason that the sciences have not accomplished what was expected of them when they acquired an assured place in the curriculum. Our science is the very foundation of agriculture—which is little more than a branch of applied chemistry—yet we are confronted with the fact that, in great agricultural states, the number of students taking Latin is many times the number in chemical courses, seven times as many throughout the country. For a fair parallel, imagine a commercial school in which the pupils deserted the rooms devoted to stenography and typewriting, and crowded to suffocation lectures on the geometry of the fourth dimension, or the metrical values of Sanscrit verse.

The future is sure to change this state of things. When tradition and inertia have been overcome, and the schools begin to render their service to the community with maximum efficiency, the subjects which stand in intimate relation to life and its needs will dominate the curriculum, and the ballast which we have inherited from a former age will occupy a subordinate position, or even disappear.

We have just examined two principles with which our teaching must, sooner or later, be brought into agreement. Let us now attempt to forecast the limitations which will be encountered when we attempt to apply these generalizations in actual teaching in the American high school.

(*a*) The plan just stated, and worked out in a typical study of the atmosphere, must not be regarded as a rigid Procrustean scheme, into which every topic must, willy-nilly, be forced, but as an ideal, to be approached quite closely in some cases, and to be departed from widely in others. The sulphides, air, and water can be handled in this way with admirable results. The next topic which naturally suggests itself, that of common salt, offers more difficulty, on account of the impossibility of extracting the

sodium from sodium chloride in the laboratory, but the method can still be used with great profit. With fluorine and its compounds, or with the hydrocarbons, the plan would be so unsuitable that sane common sense at once dismisses it as impracticable. Here we must resort to communication, vitalized by reference to familiar phenomena, by the mineral collection, and by significant laboratory and demonstration experiments. We shall see, in a moment, that, in all topics, the treatment recommended must, at some stage or other, retire and give place to systematic communication.

(*b*) "Rediscovery" is not the object of the work, and is, in general, impossible under high-school conditions. We are all acquainted with the futile and dangerous tomfoolery of the pupil who starts to investigate on his own account. Leadership there must be, and the dogmatic analytical method at its worst is far better than the anarchy of haphazard experimentation. A class simply turned loose in the laboratory would accomplish nothing, and would require the constant services of a well-equipped fire department, a good hospital, and perhaps an undertaker or two. The student who could rediscover chemical science in a year's course of five periods or so a week would be an intellectual giant beside whom men like Lavoisier and Faraday are mere insects in the dust. The teacher would be so cast down by the inevitable comparison between his own modest acquisitions and the marvels achieved by his classes that he would apply to an osteopath for treatment whenever he suffered from headache.

I insist on this elementary point on account of the exaggerated statements which are published from time to time by critics without experience in high-school teaching. Claims that the student should himself select the problem, devise the method of attack, work out in tributary researches any general principles that may be needed, and construct the apparatus required are sheer nonsense, which serves only to delay needed reforms and to provoke reactions to mechanical methods.

Take the particularly simple case of Boyle's law. The lad who was provided with a stand, meter stick, glass tubing, mercury, and *no guidance* would have about the same chance of arriving at the law as a font of type would have, when placed in a bag and shaken, of setting up the text of "The Tales of Baron Münchausen." *With* guidance, which tells him exactly what to

do, and, to all intents and purposes, what he is to observe, he is able to understand the train of thought which Boyle pursued, and to verify the law up to a pressure of about two atmospheres. Boyle himself went no further, though he did experiment with air at pressures of less than one atmosphere. This places the student in a very different position from that which he would have occupied if he had merely chanted a formula that the volume varies inversely as the pressure, but he has not *rediscovered* any general law about the conduct of gases. He has followed the track blazed for him by Boyle, and he has worked with but one gas and over a very small range of pressures. Communication must now be resorted to, if he is to know anything about higher and lower pressures, and about the behavior of different gases. Similar statements hold good with regard to the expansion of gases by heat.

The student's personal knowledge, even supplemented by the laboratory, is narrow, and must be enlarged by communication on every topic. But there is all the difference in the world between communication to the learner who has worked through concrete similar examples, and communication to the learner who has not, and who must try to find a foothold on the unsubstantial foundation of mere verbiage.

The law of constant proportions, simple as it is, is not always easily comprehended from mere description. However, a single instance—for which I employ the solution of a weighed portion of zinc in hydrochloric acid, comparing the weights of zinc chloride obtained by different students using multiple weights of zinc—suffices to render it perfectly familiar, and its application to innumerable other cases presents no difficulties.

The idea of atomic weights does not become concrete so readily. Explanation is of hardly any service here—problems are better—but I have not found it possible to give a concrete working knowledge of this indispensable idea by problems alone. The tendency to confuse atomic weight with *density* is surprisingly difficult to eradicate. To let the student determine two or three atomic weights for himself at once annihilates his perplexities. The atomic weights of copper, tin, and magnesium can be determined with sufficient accuracy in about an hour, with only the apparatus at hand in every laboratory.

In this procedure of generalizing from a few instances only,

there is nothing unscientific, for the actual investigator does exactly the same thing. No reasearch worker tests all included cases before forming his generalization. He may often set up a working hypothesis on a basis of one instance only.

4. *A Workable Scheme.*

It is time for us to profit by the experience of some of the European nations which, while behind us in laboratory facilities, are in advance of us in the arrangement of the work. The course should be divided into two distinct phases, each with its own aims and purposes.

I. THE FIRST PHASE.

The object of the first phase of the chemical work is the orderly development of the general indispensable principles of the science. Method should be supreme, chemical system and classification should be allowed no weight whatever, and the condition of the mind of the student should not be forgotten for a moment. Each topic should be started with something concrete and significant to him, or with something which can at once be rendered concrete in the laboratory, or by the aid of the mineral collection. A typical example of this kind of treatment has been sketched in connection with the atmosphere. Everything except scientific accuracy should be subordinated to the observance of the two principles already discussed. As subjects for this first course, the following naturally suggest themselves:

(*a*) A study of familiar elements which occur native, especially sulphur, carbon, and the common metals. This should include the mineral sulphides and the preparation of the metallic sulphides, and out of it should emerge the essential characteristics of a chemical process.

(*b*) A study of the atmosphere, somewhat as indicated above, which should be extended to cover combustion, carbon dioxide, etc. If not relegated to physics, the general properties of gases and the kinetic theory of matter—which is now a fact—can form the conclusion.

(*c*) Water and hydrogen, the latter being obtained not from acids, but from the water by means of zinc dust. A natural conclusion is formed by the action of hydrogen upon oxides and of carbon upon oxides, with the related metallurgical processes.

(*d*) Common salt, sodium, and chlorine. Hydrogen chloride in detail and briefer treatment of the important compounds of

chlorine with the elements already studied. The first phase can here be concluded with a concise, systematic survey of the ground thus far covered.

Symbols and formulæ can be introduced in (*b*) in connection with the oxides of the metals, the sulphides being also pressed into service. The idea of molecular weight can be adumbrated in (*c*) and fully set forth in (*d*). The essential facts of solution can be given at the beginning of (*d*) in connection with the physiographical and industrial treatment of salt, but the application of the idea of molecular weight to solutions, and the treatment of ionization and electrolysis, are best deferred.

II. THE SECOND PHASE.

In the second phase, also, the two great educational principles which dominate the whole should receive constant attention, but, since the student now has a considerable chemical experience, and quite a large store of familiar instances with which to assimilate his new acquisitions, the movement can be freer and more systematic, with somewhat less emphasis on methodological considerations. Space is lacking to enumerate the subject-matter, which includes the chemical domain which every child should know. I must confine myself simply to making a few suggestions.

(*a*) If time is available, the brief summary indicated as a suitable conclusion to the first phase can be omitted, and replaced, at the beginning of the second phase, by a more detailed and systematic study of some of the more important elements which have already been encountered. This would be the place, for example, for the production of hydrogen from acids and of oxygen from potassium chlorate, for ozone and hydrogen peroxide, and for further details regarding the chlorine compounds.

(*b*) Consider a sequence of topics like the following: lead, lead oxide, lead sulphide, lead chloride, lead sulphate, lead nitrate, lead carbonate, etc. The only connection is that all the seven materials contain lead. In the study of such a series there is an incoherence, a jerky mental movement, due to the inconsecutiveness of the arrangement, to the almost complete lack of congruity among the topics. In a hand-book such a grouping is satisfactory, because it makes it easy to find things. But there is no good reason for copying the arrangement in the presentation of a science to the beginner. Familiarity, logical order, and

congruity are the only considerations which are relevant and to which any weight should be allowed. Lead sulphide, as an important mineral which can be cheaply purchased in almost pure condition for laboratory work, finds its natural place among the sulphur compounds, near the beginning of the first phase. Lead oxide can be logically handled in connection with the action of air on the metals.

Where some systematic classification must be followed, it is usually better to group salts according to the acid radical, rather than according to the metal, for the purposes of elementary study. Thus the nitrates form a fairly coherent topic, closely connected genetically with nitric acid and with the oxides of nitrogen. The solubility relations of the nitrates can be discussed in the light of the important case of potassium and sodium nitrates, and the fixation of nitrogen forms a suitable conclusion. All this cohesion is sacrificed if the nitrates are merely scattered among the metals.

(*c*) I have elsewhere expressed the opinion that the actual value of technology to the student is greatly exaggerated in some quarters. He will more frequently have opportunity to apply the purely scientific aspects of the subject. Moreover, through no fault of the teacher, the technology of the high-school course is apt to diverge quite widely from the actual conditions in practice, which change so rapidly that the processes of the elementary text are often obsolete before the book appears in print. All of us are acquainted with the constant necessity of correcting the technology of the book we happen to be using.

As an illustration of the uncertainty of technological information, consider one point in a rather stable process—the manufacture of ordinary soda glass. In common, I suppose, with most teachers, I had been in the habit of dismissing the sodium aspect of this matter with the statement that the carbonate had been used but was largely displaced by the sulphate, which furnished the sodium more cheaply. Two years ago I learned, in conversation with a large glass manufacturer, that Chile saltpetre had almost entirely displaced the sulphate, the oxidizing action being regarded as an advantage. At present, while the imports of Chile saltpetre into the United States have not increased to any great extent, the demand for it for the nitric acid manufacture is quite unprecedented, and the glass-makers seem— to judge

from that uncertain criterion, newspaper reports—to be forced back to the use of soda ash.

The sane thing seems to be to add interest by the aid of technology, to keep the applications of chemistry to human needs before the students, but to avoid over-emphasis. Special attention should be paid to those cases in which a technical process exemplifies and clears up an important general principle. An illustration is the connection of catalysis with the manufacture of sulphuric acid, both in the lead chambers and by the contact process.

(*d*) In all these recommendations there is nothing revolutionary and nothing radically new. In Germany the abandonment of the dogmatic analytical procedure began with Arendt (1862) and Wilbrand (1870), and has been complete for a generation. In England the same movement has progressed under the leadership of Perkin and Armstrong. Since the basic idea is to proceed logically from the concrete to the abstract—and, where possible, to return to the concrete at the end of the train of thought to clinch the principle by an application significant to the student—the plan leads to an unusual attention to household matters, familiar phenomena, every-day affairs. Thus far are we in accord with those who would have us make our teaching more practical. But we wish to interpret the word not with the myopic vision of the half-educated man, who despises everything which he cannot understand, but with the wide and imaginative outlook of the man who knows that the disinterested research of to-day is the factory commonplace of to-morrow. The commercial history of the world for the last fifty years points the moral that the nation which fails to grasp the value of science, and especially of chemical science, is moving to disaster. America should learn this lesson *now*, and not through an industrial catastrophe hereafter.

The Microscopic Structure of Semipermeable Membranes and the Part Played by Surface Forces in Osmosis. F. TINKER. (*Proceedings of the Royal Society*, Series A, vol. 92, No. A641, May 6, 1916.)—Hitherto very few experimental observations have been made to arrive at some of the fundamental facts associated with the mechanism of osmosis. Raoult, Flusin, Kahlenberg, and a few others have shown, however, that certain membranes, such as parchment, gelatine, and rubber, absorb the liquids to which they are permeable, and are impermeable to liquids which they do not absorb;

Bigelow and Bartell have shown that, under certain conditions, the rate of flow of water through a membrane such as copper ferrocyanide obeys Poiseuille's law for the rate of flow through capillary tubes; while Beutner, Donnan, and others have proved that certain precipitation membranes can act as electrodes, reversible with respect to various ions. The further questions which are dealt with in the present communication are experimental ones, such as: What is the size of the colloidal particles of which a semipermeable membrane is composed, and how is the membrane built up from those particles? To what extent does a membrane show the properties of the gelatinous precipitates or gels as ordinarily prepared by bulk precipitation? How is the structure of the membrane altered by variations in the method of its formation, the nature of the solutions bathing it, and the treatment to which it is subjected? and what is the size of its pores, the extent to which they are under the control of the surface forces and therefore of absorption phenomena also?

(1) The common precipitation semipermeable membranes are composed of small precipitate particles, ranging from 0.1μ to 1.0μ, these particles being packed closely together. Each of these precipitate particles is, however, not simple in structure, but is itself an aggregate formed by the flocculation of semimicroscopic colloidal particles. The particles composing the membrane are smallest in the case of copper ferrocyanide and Prussian blue. (2) Precipitation membranes show most of the properties of gels, as ordinarily prepared, both in their method of formation and in the changes they undergo in various solutions. Like ordinary gels, they are possessed of great tensile strength, which varies in membranes of various kinds. Their stability in the colloidal condition also varies greatly. But, although they show the physical properties of gels, they have not the same mechanical structure, the membrane being much more closely knit together than the gel proper. (3) The pores in a copper ferrocyanide membrane range from 8 to 60$\mu\mu$ in diameter, the average diameter being from 15 to 20$\mu\mu$. The pore size is too great for the membrane to act osmotically by exerting a selective blocking action. (4) The order of a series of membranes in pore size is the same as that of their efficiency as semipermeable membranes. Copper ferrocyanide and Prussian blue are the most efficient membranes, and they have also the smallest pores. (5) There is also very close connection between the osmotic properties of a membrane and the extent to which the membrane capillaries are under the control of surface forces. Osmotic effects are probably the result of selective absorption phenomena occurring at the surface of the membrane and in the capillaries, the membrane being relatively impermeable to solutes which are negatively absorbed, but permeable to solutes which are positively absorbed.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

SUMMARY OF EXPERIMENTS ON THE SILVER VOLTAMETER AT THE BUREAU OF STANDARDS AND PROPOSED SPECIFICATIONS.[1]

By E. B. Rosa and G. W. Vinal.

THE investigation of the silver voltameter at this Bureau was first begun by the late Dr. K. E. Guthe, in 1904. His results were published in two papers about a year later. In 1907 the work was again taken up by Dr. N. E. Dorsey in coöperation with the present authors, but the results obtained at this time did not confirm the experiments of the National Physical Laboratory, which were then newly published, and new difficulties arose which were not understood. These experiments were not published. In the following year the work was resumed and preparations for a very thorough study of the silver voltameter were made. The voltameter received added importance when the ampère was adopted by the London Electrical Congress as the second fundamental electrical unit, so that the investigations which the present authors began in the summer of 1908 have passed beyond the original plans in scope and duration. This has also been due, in large measure, to the numerous and intricate sources of error which were discovered in the course of the work, all of which required painstaking investigation.

Other experimenters have coöperated with us during the course of the work. These were Dr. A. S. McDaniel, Prof. S. J. Bates, Prof. G. A. Hulett, and Mr. Wm. M. Bovard. The results of the investigations have been published in a series of eight papers. The present paper contains a summary of these eight papers, and the Bureau's proposed specifications for the voltameter. No adequate specifications have been adopted since the London Conference of 1908, and it is hoped that the carefully drawn specifications which the Bureau presents in the complete paper may be adopted as a whole or in part when it is possible to

* Communicated by the Director.

[1] Scientific Paper No. 285.

reach an international agreement. For the present, the specifications are available for the guidance of such investigators as wish to use the silver voltameter.

A few of the principal results of the voltameter investigations which are summarized in the present paper are the following:

1. The effect of filter-paper on silver nitrate solutions, whether the paper is used in the voltameter itself, as has been commonly done, or whether it is used in the preparation of the silver nitrate solution, was shown to be serious and to result in the formation of colloidal silver. This effect of the filter-paper is due to the formation of reducing agents from the oxycellulose of the paper itself, and is not due to impurities.

2. The appearance of the deposit is altered by the presence of impurities in the solutions (such as those resulting from filter-paper). Pure solutions give crystalline deposits of very pure silver, but colloids, if present, break up the crystals and produce striated deposits which are too heavy to accurately represent the electricity which passed through the voltameter.

3. Many forms of voltameter have been compared. The Bureau has found as the most satisfactory the porous cup voltameter, and the new form devised by Mr. F. E. Smith, of the National Physical Laboratory.

4. The Bureau has devised means of preparing pure silver nitrate and suitable tests for it, so that the electrolyte may be of a uniformly high state of purity. These tests are for acidity and for reducing agents. The Bureau has also found that the agreement of large and small sizes of voltameters, when used simultaneously, is a valuable test of purity, since impure solutions (except for acid) invariably give heavier deposits in the large-size voltameters. This phenomenon we have called the volume effect.

5. The temperature coefficient of the voltameter is found to be zero.

6. Tests on the purity of the silver deposits show that when made from pure electrolyte the impurities included with the silver crystals represent only 0.004 per cent. of the weight of the deposit, on the average.

7. The absolute electrochemical equivalent of silver was found to be 1.11800 mg. per coulomb, and the voltage of the Weston normal cell was found to be 1.01827 volts at 20° C.

8. Comparisons with the iodine voltameter were made and the ratio of silver deposited to the iodine deposited by the same current was found to be 0.85017, which, corrected for the inclusions in the silver deposits, gives 0.85013. The electrochemical equivalent of iodine in absolute measure was computed to be 1.31507 mg. per coulomb. The value for the faraday on the basis of the absolute electrochemical equivalent of silver and iodine and their atomic weights is as follows:

On the silver basis (Ag = 107.88)	96,494
On the iodine basis (I = 126.92)	96,512
Mean	96,503

The best round value which can be assigned to this constant appears to be 96,500 coulombs.

A brief history of the specifications for the voltameter which have been used in the past is given, followed by the Bureau's proposed specifications. An appendix contains an extensive bibliography of the silver voltameter.

CALCULATION OF PLANCK'S CONSTANT C_2.*

By J. H. Dellinger.

THIS constant, which is of great importance in high-temperature measurements and in atomic theory, has heretofore been obtained from radiation data by processes involving the use of a graph. It may be calculated directly and very simply from any two observations. A solution of Planck's equation for c_2 in terms of the ratio of energies at any two wave-lengths and temperatures is readily obtained, c_2 appearing in a correction term in the solution. The various relations which have been used for obtaining c_2 from radiation data are deducible as special cases.

The equation for two observations of wave-length at constant temperature is of special interest; the following approximate expression is sufficiently exact for most cases:

$$c_2 = \frac{\lambda_1\lambda_2\,\theta}{\lambda_2-\lambda_1}\left[\log\frac{J^2}{J_1}+5\log\frac{\lambda_2}{\lambda_1}-e^{\frac{c_2}{\lambda_2\theta}}\right]$$

* Scientific Paper No. 287.

An approximate value of c_2 always suffices for the last term. This general method of solution is superior to the method of equal ordinates. No curve has to be drawn, and the calculations are not limited to particular pairs of points. The method is more powerful in determining whether an observed curve fits the Planck equation. In fact, curves which give normal values for c_2 by the method of equal ordinates were found to give very high values when calculations were made by this method for two points, both on the same side of the maximum.

Points on the Planck curve for which Wien's displacement law holds, in particular the maximum of the curve, have been considered as furnishing additional ways of determining c_2. Such methods are debarred by lack of accuracy, and, in fact, these special points may themselves be obtained most accurately and conveniently by the same process of using two observations which is used for obtaining c_2. Substantially the same simple equation suffices to determine c_2 and all the special points.

WHEATSTONE BRIDGES AND ACCESSORY APPARATUS FOR RESISTANCE THERMOMETRY.*

By E. F. Mueller.

A TYPE of Wheatstone bridge, suitable for use in resistance thermometry, has been developed, in which plugs or dial switches are used, and the circuits so arranged that the errors due to contact resistances are no greater than with the mercury contact bridges heretofore used. With a comparatively simple and inexpensive type of apparatus it has been possible to attain the high degree of precision and accuracy demanded in modern work with resistance thermometers.

A method of measuring potential terminal resistances by the Wheatstone bridge method is also given, and the necessary accessory apparatus for this purpose is described. The usefulness of the bridges may also be greatly increased by the use of an interchanger, by means of which a number of thermometers may be measured in rapid succession with a single bridge.

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* Scientific Paper No. 288.

THE DAMPING OF WAVES AND OTHER DISTURBANCES IN MERCURY.*

By M. H. Stillman.

IN instruments involving the use of mercury the waves and other disturbances produced in the latter by the unsteadiness of the containing vessel are a frequent source of trouble. If a mass of mercury be subjected to a strong magnetic field, the direction of the field being approximately at right angles to the direction of motion of the mercury, this motion will be strongly damped. The motion of the mercury across the magnetic lines of force tends to produce an electric current, the reaction of which with these lines of force tends to stop the motion of the mercury.

It can be easily shown that the damping force on the mercury is given by the equation $F = K\Sigma\frac{lvB^2}{R}$ where l is the length of the element of mercury moving at right angles to the lines of force with the velocity v in a field of flux density B, and R is the resistance of the elementary circuit. K is a constant depending upon the units used.

The writer found that the substitution of a non-magnetic metallic container for a glass container greatly increased the magnitude of the damping. This was, of course, due to the decreasing of the resistance to the induced electric currents.

While this method is most effective in damping the larger oscillations and waves in a mass of mercury, since the magnitude of the damping is directly proportional to the velocity, it was found to be very effective in damping the small ripples, also.

It is suggested that this method might sometimes be used when it is desired to obtain accurate adjustments of mercury surfaces at sea and in other places where unsteadiness of the mercury container is unavoidable.

PROCEDURE IN MAKING ELECTROLYSIS SURVEYS.†

By Burton McCollum and G. H. Ahlborn.

THIS paper deals with the methods of procedure to be followed in examining underground pipe and cable systems and the return system of electric railways for the purpose of determining

* Scientific Paper No. 289.

† Technologic Paper No. 28.

the liability of the underground metallic structures to damage from stray electric currents from the electric railways. The paper describes the principal methods that have been successfully used by the engineers of the Bureau of Standards in work of this kind during the past five years.

The introduction sets forth the purpose of making electrolysis surveys, and outlines several classes of surveys that may be made according to the character of the information sought. The paper points out that by means of proper measurements it is possible to determine the extent and location of the areas in which the pipes and other structures are in danger, and the approximate degree of seriousness of the trouble. The cause of the damage in progress, whether due to stray currents or natural corrosion by soil, cinders, or organic matter, can generally be pointed out, and in case of electrolytic corrosion the source of the current can generally be definitely determined. The various factors tending to produce or aggravate electrolytic damage, such as local discontinuity or high resistance in the pipe systems, unusually low resistance soil; or, in the railway lines, poor rail-joints, infrequent cross-bonds, insufficient conductance in the negative return, improper use of such conductance, or too long feeding distances, may be determined, besides many questions of local importance. Attention is called to the fact that a large amount of preliminary data and information on the railway systems needs to be obtained prior to the making of electric measurements. These include:

1. The character of the service, whether city, suburban, or interurban. This will have a bearing on the schedule, momentary variation in load, and load factor.

2. Physical data on the railway systems, such as rail weights, types of bonds and joints used, and road-bed construction.

3. The practice of the railway company in regard to frequency of cross-bonding, bond maintenance, and bond testing.

4. Load curves are necessary for the interpretation of the data in order to reduce short-time readings to all-day or other average values. Where the load varies considerably in different sections of a power-house feeding area it may be necessary to get the load curves on different feeders as well as the total power-house load.

5. Where a survey is made with the ultimate purpose of correcting electrolysis conditions by applying some method of mitiga-

tion it will also be necessary to secure complete data on the magnitude and distribution of load, the generating and substation feeder systems, frequency of schedule, and probable future demands of traffic.

The electrical measurements required in electrolysis surveys are treated under three heads, namely: (1) Measurement of over-all potential drops between the points of lowest potential and outlying points on the railway system, potential gradient measurements in tracks and earth, and potential difference measurements between different systems of underground structures; (2) current measurements, including measurement of current in feeders and rails, measurement of current in pipes and lead cable sheaths, measurement of current leakage from buried metallic structures into the earth; (3) miscellaneous measurements, which include the location and testing of high-resistance joints in pipes, track testing, measurement of earth resistance, measurement of leakage resistance between railway tracks and earth, determination of the cause of corrosion, determination of the source of stray currents, location of concealed metallic connections, and examination of concrete structures.

There is also a section devoted to the discussion of the principles involved in the proper interpretation of the results of electrolysis test data, and the importance of having electrolysis surveys carried out under the supervision of an engineer thoroughly experienced in work of this nature is emphasized.

NOTES ON ELECTRIC RAILWAY TRACK LEAKAGE.*

By G. H. Ahlborn.

THE Bureau of Standards is issuing Technologic Paper No. 75, under the authorship of G. H. Ahlborn, entitled "Notes on Electric Railway Track Leakage." This report deals with data which were obtained as a part of the general investigation of electrolysis carried on by the Bureau of Standards. The object is to show the actual amount of leakage which may occur from street railway lines under operating conditions.

*Technologic Paper No. 75.

The physical characteristics of three suburban and interurban lines are given, and tests, conducted with the cars off the line and the concentrated load at the extreme end, described.

The first line is constructed with double tracks, the rails being imbedded in the street surface for most of the length, which is 5.5 miles. The road-bed of this line is quite well drained, and the elevation is between 200 and 300 feet.

The total leakage from this track, including that escaping from the terminal networks, is about 28 per cent. of the total current impressed, which was 300 ampères, or the leakage is 84 ampères. Calculations involving the distribution of leakage along the line show that the resistance of the track is increased 15 per cent. because of rail-joints, which is not excessive, since several isolated high-resistance joints increase the resistance, and the joints on the average are good. The average road-bed resistance for 1000 feet of single track is about 1.76 ohms.

The second line tested is single track, about 11 miles long, with the rails practically clear of ground. The elevation of this line is about 125 feet and the soil is chiefly sand and gravel, so that it drains readily. The leakage from this line amounted to 47 per cent., or, with the 150 ampères impressed, about 70 ampères. This is not as excessive as might seem in comparison with the first line, because the over-all potential drop required to force the current through this line was three times as great. However, the track was not in good condition, the joints increasing the resistance over that of the solid rail by 40 per cent. The resistance to ground was unusually high, being about 14.57 ohms for 1000 feet, or 2.75 ohms for one mile.

The third line was single track, about 6.5 miles long, with the rails generally clear of soil. However, the elevation was very low, being about 10 feet above sea level on the average, and the soil was impregnated with salt water from the surrounding marshes. The total current impressed was 205 ampères, and of this amount only 14 ampères remained on the track throughout its entire length, or the leakage was 93 per cent. Here, again, the over-all potential is high, being 87 volts, but the track was in very bad condition, the joints having increased the effective resistance to nearly 16 times what it would have been with continuous rails. For considerable distances one rail carried the entire current, and this rail had many high-resistance joints. The leakage resistance

was low, being 1.8 ohms for 1000 feet, or about 0.34 ohm for one mile.

This report emphasizes the importance of maintaining as high resistance to ground as is feasible, but especially of having a high standard of rail-bonding and cross-bonding on all lines.

THE PROPERTIES OF SOME EUROPEAN PLASTIC FIRE CLAYS.*

By A. V. Bleininger and H. G. Schuresht.

In this paper the properties of five well-known European plastic fire clays, largely used for glass pots, graphite crucibles, etc., were studied for the purpose of securing data, making possible a comparison with similar American clays. Such properties as the content of shrinkage and pore-water, drying shrinkage, fineness of grain, rate of drying, mechanical strength in the dry state, rate of vitrification, final softening temperature, and the chemical composition were determined. Tentative specifications are suggested, assisting in selecting American clays of similar properties. These include the following requirements: An extensive range of water content corresponding to a difference of about 40 per cent. between the minimum and maximum water contents, permitting of moulding the clay; an Atterberg factor of not less than 50 nor higher than 110; a ratio of shrinkage to pore-water of not more than 1 : 1.2; a total water content for normal consistency of between 30 to 45 per cent. in terms of the dry weight; a tensile strength in the plastic state close to 4 pounds per square inch; a disintegration time (in water) of not less than 50 minutes; a linear drying shrinkage of not less than 6.5 and more than 10 per cent. in terms of the dry length; a tensile strength of the clay, mixed with 50 per cent. of screened calcined clay, of not less than 150 pounds per square inch in the dried state; a modulus of rupture under the same conditions of not less than 350 pounds per square inch; a porosity of not more than 10 per cent. at 1150° C., and 5 per cent. at 1250° C., for crucible clays, constant porosity being maintained up to 1350° C. and 1400° C., respectively, for brass and steel melting, and a porosity of not

* Technologic Paper.

more than 10 per cent. at 1350° C. for glass-pot clays; a softening point corresponding to standard cone No. 30 for crucible and, if possible, higher for glass refractories; a total content of fluxes (iron oxide, lime, magnesia, potash, and soda) of not more than 5 per cent. for crucible and 4 per cent. for glass-pot clays.

From the results obtained it was shown that these famous European clays do not differ radically from similar materials found in this country, but that the same results can be obtained with mixtures of known American clays. There is no lack of domestic clays suitable for the uses under consideration, and it is but a question of proper selection. The possibility is pointed out of securing with American raw materials results even superior to those obtained with the foreign clays by mixtures of two distinct types, the open and dense burning clays. The imported clays show certain faults which may be eliminated by the systematic blending of several clays.

ELECTRIC UNITS AND STANDARDS.*

By J. H. Dellinger.

THE available information on the fundamental electric and magnetic units has hitherto been scattered over an extensive literature. The subject has been condensed and brought up-to-date in this single publication, which gives a unified treatment of the various units, standards, and systems of units. This takes the place of certain previous publications of the Bureau dealing with fragments of the subject.

A unit of any physical quantity is defined in general as a definite amount of that physical quantity, specified in some particular way. A standard is the experimental realization or representation of a unit. A system of units is based upon a few selected independent units; *i.e.*, units defined in terms of an arbitrarily chosen standard. There are three independent units in a system of mechanical quantities, and four in an electrical system.

The basis of the electric units usually used is the electromagnetic system, in which length, mass, time, and magnetic permeability are taken as fundamental. There are several systems of electromagnetic units in use, differing either in the size of the

* Circular No. 60.

fundamental units or in the constants in the defining equations. These are the C.G.S., the so-called "practical," and the Heaviside units. The units used in practice are the "international" units, so called by the international congresses which defined them. They represent the electromagnetic units for practical purposes, and the fundamental international units were so defined as to be equal to the corresponding electromagnetic units as closely as known at the time of definition. The slight differences which have been found by absolute measurements are tabulated in the circular, for the convenience of the occasional investigator who may desire to convert from one system to the other.

The system of concrete standards by which the electric units are now maintained is the result of an evolution extending over 70 years. The units are maintained by the national standardizing laboratories in accordance with the decisions of the 1908 International Conference at London.

The circular gives the definitions of the units and detailed information regarding the units and standards of resistance, current, electromotive force, quantity of electricity, capacity, inductance, power and energy, resistivity, and the magnetic quantities.

In an appendix, conversion factors for the above units are given, both for units of different systems and for the international units as maintained at different times and places. The laws on electric units in different countries are given. A selected bibliography of the literature pertaining to electric and magnetic units and standards is included.

Successful Under-water Coal Storage. J. D. WARDLE. (*Electric Railway Journal*, vol. xlvii, No. 26, June 24, 1916.)—The Iowa Railway and Light Company, which operates about fifty miles of interurban line and has more than 350 miles of high-tension distribution, serving lighting and power consumers in central Iowa, has recently put into service a large under-water coal storage. Iowa coal when piled ignites itself readily, and it is, therefore, necessary to store it in a flooded pit. The coal is reclaimed from the pit with a 15-ton electric locomotive crane. With a consumption of coal of 250 tons a day, it was formerly necessary to carry 5000 or 6000 tons in reserve in cars at a *per diem* charge of 45 cents. With under-water storage the number of reserve cars has been reduced to ten and the daily charge from $45 to $4.50.

Leak Loading of Telephone Lines. ANON. (*Electrical Review*, vol. 68, No. 26, June 24, 1916.)—In the field of wire telephony the series loading of the line with inductors greatly enlarged the possibilities of long-distance telephony. In consequence this subject has been very fully investigated. The leak loading of telephone lines has not proved to be of commercial importance, and little has been published upon the subject, although it is quite possible that the engineers of commercial and operating companies have fully investigated its possibilities from the theoretical standpoint. Lines of this character have been proposed for telephony and cable telegraphy, but their characteristics have not proved favorable.

Prof. Arthur E. Kennelly, of Harvard University and the Massachusetts Institute of Technology, who has worked out the relations involved in leak loading and has developed two new formulas for expressing these relations, contributes a paper on the subject. By taking advantage of the mathematical similarity of the expression for admittance as affected by leaks and the expression for impedance as affected by series inductance, he has reduced the two problems to calculations of the same kind. Numerical examples are given to show the application of the very simple formulas which have been derived. Professor Kennelly is an ardent advocate of the use of hyperbolic functions in electrical computations, and gives here a very good example of the very great advantage and simplicity obtained by their application.

A New Method for Enlarging Photographs Without the Use of a Lens. A. J. LOTKA. (*The Physical Review*, vol. vii, No. 6, June, 1916.)—The method consists in moving the negative to be enlarged past a narrow-slit source of light and, at the same time, moving a sensitive plate under the negative at a speed equal to some constant multiple, n, of the speed of the negative. On development of the sensitive plate, a positive transparency is obtained in which all the lines which were parallel to the slit during the exposure are unaltered, while all lines at right angles to the slit are magnified in the ratio $n : 1$. The positive so obtained is subjected to a repetition of the process employed with the original negative, but with the motion at right angles to the lines drawn out n-fold in the first operation. The result of the second operation is a negative geometrically similar to the original, but with the linear dimensions enlarged n times.

Among the advantages which the new method presents is uniformity of illumination over the entire field, absence of optical distortion, compactness, simplicity, and low cost of apparatus. The process necessitates two successive exposures, but this is true, also, of the ordinary method when a negative is to be prepared from a negative. The process and apparatus are protected by U. S. Patent 1,176,384 of March 21, 1916, issued to the author.

NOTES FROM THE NELA RESEARCH LABORATORY.*

NOTES ON FLICKER PHOTOMETRY: FLICKER-PHOTOMETER FREQUENCY AS A FUNCTION OF LIGHT INTENSITY.

By Leonard T. Troland.

THE measurements reported below were partly incidental to some other work, but were thought sufficiently interesting to merit publication.

The conditions of observation were similar to those described in a previous note on the same general subject,[1] except that the standard light consisted of uncorrected tungsten radiation, and a wide range of intensities was employed. The variation of intensity was accomplished by changing the voltage across the standard lamp, so that along with the intensity change there was also an alteration in color. At the highest intensity (1560 photons) the lamp was operating at 1.87 watts per mean spherical candle, and 4.32 volts, while at the lowest intensity (6.4 photons) the voltage across the lamp was 1.33.

The following table shows the flicker-photometer frequencies found under these conditions for eight spectral colors, at the several intensities:

Color	Wave-length in $\mu\mu$	Flicker-photometer frequency, cycles per second, for an intensity (in photons) of						
		6.40	16.0	40.0	100.0	250.0	625.0	1560.0
Red	676.4–700.0	8.90	10.66	12.96	16.58	20.78		
		(A.D.) .02	.08	.05	.12	.10		
Orange	614.4–631.0	10.18	11.76	13.62	16.16	19.74	24.12	28.06
		(A.D.) .04	.09	.10	.05	.08	.10	.12
Yellow	569.2–582.0	8.52	9.10	10.26	11.74	14.42	16.52	21.02
		(A.D.) .05	.05	.06	.07	.08	.15	.50
Yellow-green	534.6–545.0	11.52	13.84	14.78	17.74	19.72	21.66	24.32
		(A.D.) .05	.15	.03	.10	.09	.06	.13
Green	500.5–509.0	10.30	11.98	13.70	16.56	20.12	22.28	28.08
		(A.D.) .02	.04	.05	.04	.06	.11	.12
Blue-green	485.4–493.0	12.34	13.86	16.34	19.48	23.06	26.40	
		(A.D.) .08	.15	.05	.19	.06	.13	
Blue	465.0–485.0	13.20	14.60	16.48	19.18	22.02	26.02	29.86
		(A.D.) .07	.13	.06	.08	.08	.05	.17
Violet	424.0–436.7	13.02	15.38	18.02	19.66	22.90		
		(A.D.) .13	.17	.08	.10	.18		

* Communicated by the Director.

[1] JOURNAL OF THE FRANKLIN INSTITUTE, vol. 181, No. 6, p. 853.

Each of the values given in the table is the average of five determinations, and the deviation measures are those of the averages themselves.

If the logarithms of the frequencies for any one color are plotted against the logarithms of the intensities, the resulting curve is approximately a straight line for intensities between 40 and 1560 photons. The deviations from straightness below 40 photons are largest for the longer wave-lengths, and are probably to be attributed to the marked orange hue of the standard at these lower intensities. It follows, therefore, that if n is the flicker-photometer frequency, and I the intensity, the relation $n = bI^a$ is approximately true, where b and a are constants. It should be noted that this equation is of quite a different form from that holding for *critical* flicker frequency.

Calculation of the values of these constants for each of the eight colors, on the basis of a representative straight line drawn through the points lying above 16 photons, gives the following results:

Constant	Color							
	Red	Orange	Yellow	Yellow-green	Green	Blue-green	Blue	Violet
b.....	4.9	6.7	4.4	9.3	6.4	8.5	9.1	10.8
a.....	.263	.196	.212	.134	.203	.180	.162	.134

It will be noticed that b increases, while a decreases, as wave-length decreases. Although the present measurements are probably sufficiently careful to support this approximate generalization, further work will be necessary to explain the deviations from it. The measurements reported in the previous note indicate that the alteration in the color of the standard, occasioned by the reduction of voltage in decreasing the intensities, has only a second-order effect upon flicker-photometer frequency at intensities in the neighborhood of 500 photons. At lower intensities the effect may be greater.

This work is being repeated under improved conditions.

July 10, 1916.

Corrigenda.—In the article "The Heterochromatic Brightness Discrimination Threshold" (under "Notes from the Nela Re-

search Laboratory"), in the July (1916) number of this JOURNAL, the following changes should be made: On page 113, third paragraph, delete "mentioned." Same page, last paragraph: "v is average of the mean variations of the four intensities, a, b, c, and d; $\Delta I/S$ is expressed as fractions of these intensities;" should read: "v is the average of the mean variations of the four intensities, a, b, c, and d, expressed as fractions of these intensities."

COMPARISON OF THE INTENSITY OF OXIDATION IN LUMINOUS AND NON-LUMINOUS INSECTS.

By W. E. Burge.

THE object of this investigation was to determine if oxidation in luminous insects, such as fire-flies, is more intense than in non-luminous insects, such as moths, butterflies, honey-bees, and bumble-bees, and if oxidation in the luminous tail end of the fire-fly is more intense than in the non-luminous portion.

Method.—The amount of oxygen liberated in 10 minutes from 30 c.c. of hydrogen peroxide by 30 milligrammes of the insect ground up in a mortar with a small amount of sand was taken as a measure of the intensity of the oxidative process of the insect. Burge has shown that tissues in which oxidation is very intense liberate larger amounts of oxygen from hydrogen peroxide than tissues in which oxidation is less intense. The hydrogen peroxide solution used was prepared by diluting the ordinary commercial hydrogen peroxide with an equal volume of distilled water. The apparatus used was an ordinary 100-c.c. burette filled with water to the zero marking and inverted with its mouth in a pan of water. The oxygen gas was conducted into the mouth of the burette by means of a rubber tube from a bottle where the gas was generated when the ground material was mixed with the hydrogen peroxide. The amount of oxygen was read off directly from the burette where it had displaced the water. After this volume had been reduced to standard atmospheric pressure the resulting volume was taken as the amount of oxygen liberated by the material from the hydrogen peroxide.

Experiments.—Thirty milligrammes of fire-flies previously ground up in a mortar with sand were introduced into the bottle containing the 30 c.c. of hydrogen peroxide, and the amount of

oxygen liberated in ten minutes was determined. Ten such determinations were made with an average of 118 c.c. of oxygen for the determinations. The smallest amount obtained in these determinations was 112 c.c. of oxygen, the largest amount 126 c.c. Similarly, 30 milligrammes of a moth were introduced into 30 c.c. of hydrogen peroxide and the amount of oxygen liberated determined. The amount of oxygen liberated by the moth was 8 c.c. of oxygen per 30 milligrammes of material. Determinations were also made using honey-bees, bumble-bees and butterflies. The amount of oxygen liberated in none of these determinations exceeded 25 c.c. of oxygen per 30 milligrammes of material. Thirty milligrammes of the luminous part of fire-flies were cut off and ground up. This part liberated 145 c.c. of oxygen from 30 c.c. of hydrogen peroxide, whereas the same amount of the ground-up non-luminous part of the fire-flies liberated 115 c.c. of oxygen from hydrogen peroxide.

Conclusions.—From the foregoing experiments it may be concluded that the oxidative processes of luminous insects, such as the fire-fly, are much more intense than of non-luminous insects, such as the moth, butterfly, etc.; that the oxidative processes in the luminous part of the fire-fly are probably more intense than in the non-luminous part.

NELA PARK, Cleveland, Ohio, July, 1916.

THE MODE OF ACTION OF ULTRAVIOLET RADIATION IN PRODUCING STERILIZATION.

By W. E. Burge.

IT has been recognized for several years that when living cells, such as bacteria, are exposed to ultraviolet radiation they are killed in a few minutes. Since the life of a cell is dependent upon its intracellular enzymes, and since the ultraviolet radiation destroys enzymes, a theory has been advanced that ultraviolet radiation kills living cells by destroying the enzymes of the cell.

The object of this investigation was to determine if the intracellular enzymes in bacteria are destroyed when the bacteria are killed by exposure to ultraviolet radiation. The bacteria used were pure cultures of *B. prodigiosus*, *B. fluorescens*, *B. liquefaciens*, *B. pyocyaneus*, *B. proteus vulgaris*, and *B. subtilis*. These

bacteria were chosen because they possess the property of liquefying gelatine, this property in turn being dependent upon the intracellular proteolytic enzymes. Twenty-five cubic centimetres of liquid containing great numbers of *B. prodigiosus* were exposed in an open vessel to the radiation from a quartz-mercury vapor burner operating at 140 volts, 3.3 ampères, at a distance of 10 cm., until the bacteria were dead. By means of a centrifugalizing machine the dead bacteria were thrown down and washed in physiological saline. The mass of dead bacteria was ground up in a mortar with sand and 30 per cent. alcohol. In this way the intracellular enzymes were extracted from the dead bacteria. All of the bacteria named above were treated after this manner. Ten cubic centimetres of the alcoholic extract of the different kinds of dead bacteria were introduced into separate test-tubes containing gelatine. Ten cubic centimetres of liquid containing the different kinds of living bacteria were also introduced into tubes containing gelatine. These tubes were permitted to stand at room temperature for 96 hours. At the end of this time the extent to which the gelatine had been liquefied in the different tubes was measured. The extract of dead *B. prodigiosus* had liquefied 7 mm. of gelatine; *B. fluorescens*, 6 mm.; *B. liquefaciens*, 10 mm.; *B. pyocyaneus*, 4 mm.; *B. proteus vulgaris*, 5 mm., and *B. subtilis*, 4 mm. The gelatine in the tube containing living *B. prodigiosus* was liquefied 8 mm.; that containing living *B. fluorescens*, 6 mm.; *B. liquefaciens*, 12 mm.; *B. pyocyaneus*, 5 mm.; *B. proteus vulgaris*, 6 mm., and *B. subtilis*, 4 mm. If the amount of gelatine liquefied by the living bacteria be compared with that liquefied by the extract of the corresponding dead bacteria, it will be found that there is very little difference in the extent of liquefaction. This is taken to mean that, while the ultraviolet rays had killed the bacteria, it had affected very little their intracellular enzymes. These experiments would seem to render untenable the theory that ultraviolet rays kill living cells by destroying their intracellular enzymes.

NELA PARK, Cleveland, Ohio, July, 1916.

Application of a Polar Form of Complex Quantities to the Calculation of Alternating-current Phenomena. N. S. DIAMANT. (*Proceedings of the American Institute of Electrical Engineers,* June 27–30, 1916.)—In the *calculation* of alternating-current phenomena by means of complex quantities, as a rule, the rectangular components of the vector are used, and the rectangular form involving the operator $j = \sqrt{-1}$ is more common than the polar or exponential forms which involve the operators $(\cos\theta + j \sin\theta)$ or $e^{j\theta}$; although it is recognized that the latter are very convenient in certain cases.

A simple method of dealing directly with the vectors themselves is described in the paper, and it consists in introducing the operator j^n, where n, contrary to ordinary usage, may be any positive or negative fraction. Just as j or j^1 rotates the quantity before which it is placed through 1×90 degrees, so j^n rotates the number into which it is multiplied through $n \times 90$ degrees. The operator j^n follows the rule of ordinary algebra, and, according to these, the different algebraic operations of multiplication, etc., are developed. A few illustrative problems are given, followed by a critical *résumé*. A summary of formulas and bibliography are included.

Extinguishing Oil Tank Fires with a Blanket of Foam. ANON. (*Scientific American,* vol. cxv, No. 2, July 8, 1916.)—There is only one effective way to extinguish an oil fire, and that is to smother it; in other words, to cover the burning oil with a suitable form of blanket that will completely cut off the supply of oxygen which is essential to combustion. In the protection of its oil tanks against conflagration the Standard Oil Company of California has met this requirement by developing a liquid extinguisher, which it calls "fire foam." Fire foam is formed by two separate liquors which, when mixed together, result in a thick spume, which readily spreads over a wide area and effectively shuts off the oxygen supply of the burning oil. The two liquids must be separately stored and brought together only just prior to the time when the foam blanket is desired in the blazing tank.

The fire-foam liquors are led through a mixing pipe and discharged through tee heads above the surface of the oil at the centre of the tank, issuing from the outlets in the form of a thick liquid of creamy appearance. The foam rapidly spreads out over the surface of the blazing oil, bubbling as would a huge caldron of dense, boiling liquid. Here and there the flames are seen to reduce in size, eventually to be smothered entirely as the foam blanket becomes more dense. In the period of about a minute the fire is completely extinguished.

SIR WILLIAM RAMSAY.

BIOGRAPHICAL NOTE.

On Monday, July 24, the cables apprised us of the death of Sir William Ramsay, the most distinguished British chemist of our time. This sad news did not come as a surprise to his many friends in this country, for they knew that for several months past he had been bravely fighting against a serious malady. With the passing of Sir William science loses one of its most resourceful experimenters, as well as a most daring prognosticator: one of those investigators who, to use his own phrase, "angle for salmon, but do not fish for sprats." Rather than being satisfied with a sure catch of small fry, he always preferred to take his chances in fishing for a great prize. In some cases he may have mistaken the place where to fish, while in others, perhaps, he used the wrong fly; but, on the whole, the catches he made were of the kind that the most expert angler might well be proud of. His experimental researches in inorganic and physical chemistry extend over a wide range of subjects, although, for the most part, they proceeded from the train of reasoning that led him to the discovery of argon.

He was born in Glasgow, October 2, 1852, and received his early education in the Glasgow Academy. His training as a chemist he acquired in the Universities of Glasgow and Tübingen, at the latter place under Lothar Meyer, who exerted a profound influence upon the young Scotsman's scientific reasoning and imagination.

In 1872 he became assistant in technical chemistry in Anderson's College, and two years later tutorial assistant in the University of Glasgow. While occupying this position his novel and effective methods of laboratory teaching attracted the interest of British educators, and in 1880 he accepted an appointment as Professor of Chemistry in the University College at Bristol. Seven years later he removed to London, where he occupied the chair of chemistry in the University College until his retirement, in 1913, as Professor Emeritus.

It was during the first twenty years of his incumbency of this chair that he made his great discoveries and published his most important books and essays. The only exception is a little laboratory manual for beginners, entitled "Experimental Proofs of

Chemical Theory," which was published about 1880. The simple quantitative methods described in it were promptly and widely adopted both in England and in this country, and may be said to have wrought a revolution in our elementary instruction in chemistry. In 1891 he published an "Elementary Systematic Chemistry," at that time a very novel and valuable treatise on the subject. But his fame as a discoverer dates from 1894, when he joined forces with Lord Rayleigh, the distinguished physicist, in unravelling a mystery disclosed by the latter's researches on the density of nitrogen, and demonstrating that atmospheric air contains the previously unknown gaseous element argon. For the masterly monograph on this subject, describing the discovery and the properties of that most remarkable inert element, the two British investigators were awarded by the Smithsonian Institution the Hodgkins Prize of $10,000, as the most valuable contribution at that time to our knowledge of the atmosphere. The search for argon in terrestrial sources, other than atmospheric air, then led Professor Ramsay to another, and no less important, discovery—that of the gaseous element helium, so called because its spectrum had previously been observed in the photosphere of the Sun (helios). In pondering over the similarity of the characters of the two new elements and their relative atomic weights, Ramsay concluded that there must be other members of the same family in the Periodic System, and that most probably they should also exist in the atmosphere. In the meantime machines had been invented by Professor Linde and by Doctor Hampson for liquefying air and other gases on a large scale by the method of self-intensive refrigeration. Taking advantage of these inventions, Ramsay liquefied large quantities of argon and enormous masses of air, and then subjecting the liquids to careful fractional distillation succeeded in separating from them three new gaseous elements, which he named neon, krypton, and xenon, as well as helium. A careful study of these gases by Ramsay and his co-laborers, especially Doctor Travers, established the fact that they, together with argon, constitute a family in the Periodic System of the chemical elements. Owing to the absolute chemical inertness of these gases, they have thus far found no practical uses, except in a small way, argon being employed in filling certain electric-light bulbs, and helium instead of air or hydrogen in gas thermometers. For this reason, no doubt, these most remarkable

discoveries of Sir William Ramsay have not gained such widespread popularity as some of his later announcements which are less firmly established by experiment, and despite the fact that he has written a most entertaining popular account of this work in "The Gases of the Atmosphere."

About the beginning of the present century the scientific world was startled by the discovery of an entirely new and most remarkable class of substances which have since come to be known as radio-active elements. They differ from the inert gases discovered by Ramsay by their wonderful and continuous activity in sending out rays and "emanations." But the fact that they, too, were obtained from pitchblende—the mineral in which Ramsay had discovered helium—and, further, that the gaseous emanations of radium were chemically inert, suggested to Sir William that these gases might belong to the argon family. So forthwith he proceeded to procure radium compounds, and to prepare and study their gaseous emanation. The circumstance that this radium gas is obtainable only in minute amounts and constantly disintegrating made this work extremely difficult; nevertheless, Sir William and his co-workers (F. Soddy, Cameron, and others) overcame all experimental difficulties, and showed that the emanation obeys the gas laws, that it can be liquefied and solidified, and that it undergoes and causes the most remarkable chemical changes. It was conclusively ascertained by Ramsay and Soddy that the gas in disintegrating produces helium, the first recorded instance of the transformation of one chemical element into another. Although this observation was doubted in many quarters, it has since been verified by independent observers in different countries.

The later researches of Sir William Ramsay proved that radium gas or niton (as he called it) belongs to the argon group. His very numerous researches on the products resulting from its radio-active effects on compounds of various metals and on other gases are highly suggestive, but by no means conclusive. His announcement that he had succeeded in converting copper, for instance, into lithium and other alkali metals, and that he had obtained gases like helium and neon by the aid of electric discharges on hydrogen, etc., have not been confirmed, and, in one instance at least, his assertion has been disproved.

We may hope, however, that this line of work (*i.e.*, the efforts to solve the problem of the transformation of chemical elements

into others, and perhaps even of transmuting the baser metals into the precious) may some day be carried out successfully, and along the lines indicated by the great British chemist.

So far as actual achievements are concerned, his fame is secured by the great experimental researches on the inert gases of the atmosphere and of the radium emanation.

In addition to the books already mentioned, Sir William Ramsay had published a charming volume, entitled "Essays, Biographical and Chemical."

I need hardly mention that his great achievements were recognized in every land where science is cultivated. He was a corresponding member of the great academies, and an honorary member of numerous learned societies. He was Nobel Laureate in Chemistry, and received numerous medals and decorations, among them the Elliott Cresson Medal of The Franklin Institute.

HARRY F. KELLER.

Dissolved Acetylene for Welding. K. DUNHAM. (*Acetylene Journal*, vol. xviii, No. 1, July, 1916.)—Dissolved acetylene, or, as it is more commonly called, tank acetylene, is in wide use by all classes of users. Here gas is bought in ready-made form, ready for use, by the opening of a valve. Care is exercised by the manufacturer of dissolved acetylene to purify it before it is compressed into the cylinder. These cylinders vary in size, according to the needs of the user, from 100 to 500 cubic feet capacity. Since acetylene is dangerous under pressure in a free state, the method of eliminating this hazard is interesting. The cylinder is filled with a porous material, and then acetone, a very volatile liquid, is poured into the cylinder. This acetone absorbs the acetylene, and, as there is no free space in the tank, no danger is encountered in handling or using acetylene furnished in this way.

Acetylene should not be withdrawn from the tank at a rate fast enough to bring out with it the solvent liquid, which is harmful in its effects on molten metal. The flame used should not require an acetylene consumption at a greater rate per hour than one-seventh the capacity of the tank; that is, a 100-foot cylinder should last seven hours. It is for this reason that steel welds made with acetylene from an automobile lighting cylinder are so often unsatisfactory. The gas in automobile cylinders costs more than that in the regular-size welding tanks, and, except in emergencies, the automobile cylinder should never be used. If it is necessary to employ these cylinders instead of welding cylinders it is advisable to connect three or four on a manifold to eliminate the possibility of the withdrawal of the acetone.

THE FRANKLIN INSTITUTE

MEMBERSHIP NOTES.

NECROLOGY.

Mr. Ira D. Bertolet was born at Weissport, Pa., on January 8, 1865, and died on June 19, 1916. He was a member of the Union League, Old York Road Country Club, Philadelphia Chamber of Commerce; a trustee of Albright College, Myerstown, Pa., for about five years, and a trustee of the Christ United Evangelical Church, Philadelphia. Mr. Bertolet became a member of The Franklin Institute in 1907.

Dr. Elmer Lawrence Corthell was born September 30, 1840, at Whitman, Mass., and died at Albany, N. Y., May 16, 1916. He was educated at Brown University, where he received the degrees of Bachelor of Arts, Master of Arts, and Doctor of Science.

He began his career as a civil engineer at Providence, R. I., in 1867. In 1868 he went West and devoted the next two years to railroad work. He was in charge of the construction of the bridge over the Mississippi River at Hannibal, and later served as chief engineer in charge of the construction of the jetties at the mouth of the river. With Mr. Eads, Dr. Corthell went to the Isthmus of Tehuantepec and made surveys for an interoceanic ship-railway. After returning to the United States he spent considerable time in promoting the Eads project for an interoceanic route. The period from 1887 to 1890 was devoted to the design and construction of bridges, railroads, and other large engineering enterprises.

The three succeeding years were devoted to consulting work for the Illinois Central and the Atchison, Topeka and Santa Fé Railway.

Dr. Corthell made extensive improvements in the harbor of Tampico, Mexico, for the Mexican Central Railroad, and was subsequently awarded the Telford Premium and the Watt Medal by the Institution of Civil Engineers of Great Britain for the paper describing this work, which he presented to that body in 1885.

For five years Dr. Corthell was consulting engineer for the Argentine Government, and for eleven years he was engineer for the Boston, Cape Cod and New York Ship Canal.

Dr. Corthell wrote many papers on professional subjects, and was an active member of practically all the important engineering and scientific societies of this country and abroad. He became a member of the Institute in January, 1914.

Prof. Augustus Jay Dubois was born at Newton Falls, Ohio, on April 25, 1849, and died at New Haven, Conn., October 19, 1915.

He received the degrees of Bachelor of Philosophy from Yale University

in 1869, Civil Engineer in 1870, and Doctor of Philosophy in 1873. During the years 1872 and 1873 he attended the Mining Academy in Freiberg, Saxony.

He became Professor of Civil and Mechanical Engineering at Lehigh University in 1875, and in 1877 was appointed Professor of Mechanical Engineering at the Sheffield Scientific School of Yale University. Since 1884 he had been Professor of Civil Engineering at the same institution.

Professor Dubois was the author of a number of works on engineering subjects, and translated and edited the Engineering Classics of Weisbach, Weyrauch, and Röntgen. He was a member of the leading engineering and scientific societies of the world.

Professor Dubois became a member of the Institute on December 20, 1898.

Mr. Charles William Henry Kirchhoff was born at San Francisco, Calif., on March 28, 1853, and died at North Asbury Park, N. J., July 23, 1916.

He obtained his technical education at the Royal School of Mines, at Clausthal, Germany, and graduated in 1874. For three years he was engaged in chemical work in Philadelphia, later becoming managing editor of a metallurgical publication. In 1878 he joined the staff of *The Iron Age*, and in 1881 he became managing editor of the *Engineering and Mining Journal*. Three years later Mr. Kirchhoff returned to *The Iron Age*, first as associate editor and later as editor-in-chief. He retired from the latter position in 1910.

For twenty-three years Mr. Kirchhoff acted as special agent of the United States Geological Survey for the collection of statistics of the production of lead, copper, and zinc.

He was a member of the American Iron and Steel Institute, the Iron and Steel Institute of Great Britain, the American Society of Mechanical Engineers, The Verein Deutscher Eisenhüttenleute, and the Engineers' Club (New York). Mr. Kirchhoff was elected an honorary member of The Franklin Institute in 1899.

Dr. Francis Wyatt was born at Portsmouth, England, in 1854, and died at Forest Hills Gardens, Long Island, on February 27, 1916. He received his early education in his native city, and later studied at the Universities of Brussels and Paris, paying special attention to agricultural chemistry. He came to the United States in 1885, where he established himself as a fermentation chemist and founded the National Brewers' Academy and Consulting Bureau, of which he was president for a number of years.

Dr. Wyatt was known throughout the United States, as well as in Europe, as an eminent authority on the chemistry and biology of fermentation, and won for himself the highest reputation as a brewers' consultant, owing to his wide experience and masterly knowledge of all technical and scientific subjects connected with the fermentation industry. He was an indefatigable worker, student, writer, and lecturer, and his charming personality was such as to immediately attract all those who came into contact with him professionally or socially. Many valuable papers were contributed by him to American and European technical journals relating to theoretical and practical questions of the fermentation industry.

Dr. Wyatt was a member of the Chemists' Club, New York, the American Chemical Society, the Society of Chemical Industry, the Association for Advancement of Science, the American Institute of Mining Engineers, and the British Institute of Brewing. He was an honorary member of the United States Brewers' Association and the Belgian Brewers' Association. He was also a member of the Lambs' Club, New York, the Algonquin Club of Boston, and the University Club of Philadelphia. Dr. Wyatt became a member of the Institute on April 7, 1894.

M. Miguel de Teive e Argollo, Secretary of State, Department of Agriculture, State of Bahia; Member of the Institution of Civil Engineers of London; Commander of the Order of the Rose, died at Paris, France, May 14, 1916. M. Argollo became a member of the Institute in August, 1902.

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An Unprepared Test of a Small Fire Extinguisher. ANON. (*Electrical Railway Journal*, vol. xlvii, No. 26, June 24, 1916.)—The ready advantages of the type of small fire extinguisher containing volatile liquid of low conductivity to electricity were well demonstrated in an accidental manner on June 5, when a fire broke out in the motor windings of an Omaha street car. According to the *Omaha World-Herald*, prompt action with one of these extinguishers subdued the blaze with practically no damage and the car was able to proceed. This result would doubtless have been impossible by using water, which, furthermore, would have been dangerous on account of its property as a conductor of electricity. (Carbon tetrachloride is said to be the liquid employed in one design of these extinguishers.)

CURRENT TOPICS.

Testing Detonators. ANON. (*Mining and Scientific Press*, vol. 112, No. 25, June 17, 1916.)—A detonator is a blasting cap or copper capsule containing a small quantity of some explosive compound that is ignited by a fuse. An electric detonator is one that is ignited by a small wire that becomes heated to incandescence, or fused, by the passage of the electric current. Fulminate of mercury is a well-known detonating agent. It may be mixed with 10 or 20 per cent. of potassium chlorate, and tests have shown that the fulminate alone is inferior to a 90 : 10 mixture, which in turn is inferior to an 80 : 20 mixture.

The United States Bureau of Mines employs "sand tests" for determining the relative efficiencies of detonators. A uniform clean quartz sand of 30 or 40 mesh is employed. The sand is placed in a small steel case, which has thick walls and a cover. The detonator is fired in the centre of a mass of 100 grammes of standard sand placed within the cavity. The extent to which the sand is pulverized by the detonation, as measured by screening tests, indicates the efficiency of the detonator. It has been assumed that a high speed of detonation is an essential property of a detonator. This is not so. Many explosives, such as blasting gelatin and nitroglycerin, have a higher velocity of detonation than fulminate of mercury, but they have not the property that fits them for use as initial detonators. It appears that the explosion of mercury fulminate results in an intense local action in the form of a sudden blow.

Former methods of making tests, in which the detonators were fired in lead blocks or their influence tried on other detonators at various distances, had proved unsatisfactory, the sand test being now preferred for careful work. However, a simple test can be made with a 4-inch wire finishing nail. The detonator is fired in proximity to the nail, and the resultant bend in the nail indicates the strength of the explosion. The strength of fulminate detonators is said to be unaffected by becoming moist, although detonators of trinitrotoluene are weakened by moisture. The trinitrotoluene detonators may become entirely unserviceable after storage for a month in a damp magazine.

Prevention of Dust Explosions and Fires in Grain Separators. ANON. (*Weekly News Letter*, U. S. Department of Agriculture, vol. iii, No. 43, May 31, 1916.)—As a result of a study of explosions in threshing machines, the department now recommends that one or more of three measures be adopted to prevent loss from this cause.

These are: (1) The installation of an efficient grounding system for the removal of static electricity from the machine; (2) the installation of a suction fan to remove smut and dust and to prevent the formation of an explosive mixture of dust and air while the threshing is being carried on; and (3) the installation of a device to act as an automatic fire extinguisher which in the event of fire will not only save the machine but will prevent the flames from spreading to the surrounding grain.

The first two of these devices have been tried with successful results in the field. The automatic fire extinguisher was not constructed until the threshing season had been closed, but it has been tested under severe conditions in the explosion galleries of the Bureau of Mines at Pittsburgh, and in these tests it has operated successfully. It has also been tested under practical threshing conditions at the government farm at Arlington, and has proved effective in extinguishing fires which were produced in different types of grain separators there. Blue prints of each of these devices may be secured upon application to the office of Public Roads and Rural Engineering of the department at Washington.

The best method, the investigations indicate, for carrying off any static electricity that may be produced is to connect wires from all moving parts on the machine to one wire and to ground that wire. The suction fan is arranged to exhaust from above the cylinder and also from beneath the pan. While it is pointed out that there is no way of absolutely demonstrating that either the grounding of the machine or the suction fan actually prevents explosions, the fact remains that no such occurrences have taken place, so far as is known, with separators that were properly equipped in this way. These devices, however, do not remove all danger from fire, for, in addition to electric sparks, foreign materials which find entrance into the separator may start fires, and for this reason the automatic fire extinguisher is regarded as a desirable additional protection.

Theory and Practice in the Filtration of Water. W. CLEMENCE. (*The Journal of the Institution of Mechanical Engineers*, May, 1916.)—Open sand-filters for purifying waters for potable purposes have now been in use for nearly a century, and since 1830 they have been continuously used in connection with the London water supply. The first sand-filtration plant, designed by James Simpson for the Chelsea Water Company, consisted of decanting basins in which the raw water could be kept at rest for twelve hours, and open filter-basins in which a layer of fine sand 2 feet 6 inches deep was placed on a bed of gravel of about the same thickness. In the gravel bed brick collecting drains with arched covers were constructed. These large drains were found to induce a too rapid flow of water through the sand immediately over them, and in later practice smaller drains were used which were distributed over the whole area of the floor of the filter to secure an even speed through the bed.

During the last twenty years what is known as the "mechanical filter" has been introduced, in which the arrangement of filtering material differs little in section from that adopted in open sand-beds, but the water under treatment is passed through the materials at a speed from twenty to sixty times greater than that which has been found in practice to represent a safe limit of speed with slow sand-filters in order to obtain complete purification of the water. This limit is generally agreed upon to be from 50 to 75 gallons per square foot per 24 hours, and it is obvious that if the process of purification is found to be incomplete in the slow filter, on exceeding this speed it must be more so in the rapid filter.

With filters of fine sand working at a slow speed it is found that practically all matters in suspension in the water, whether living organisms or silt particles, are retained on the surface of the filtering medium, where they eventually form an impervious layer, and it becomes necessary to remove this in order to restore the permeability of the bed. It has been established in practice that with filters on which a filtering layer is allowed to form the efficiency of the filter is impaired if the layer is disturbed, and that after its complete removal when the filter is cleaned the chemical and bacterial efficiency is not restored until a film has again formed.

Much attention has been paid by engineers in recent years to the improvement in the conditions of working and the design of filters, resulting in the formation of two distinct methods of practice, based on widely divergent theories. On the one hand, those who support the theory that the bacterial purification of water by filtration is chiefly due to the mechanical action have developed the mechanical filter, in which a film is created artificially by the use of a coagulant, and a high speed is adopted. On the other hand, Armand Pusch proved by experiment and observation that the formation of a film on the surface of a filter was a hindrance rather than an aid to purification, and Pusch and Chabal have developed the system of multiple filtration, which is founded on the now ascertained fact that the formation of a film, either natural or artificial, on the surface of the filtering medium is unnecessary and undesirable.

New Car for Fish Distribution. ANON. (*United States Commerce Reports*, No. 159, July 8, 1916.)—A new car for the Bureau of Fisheries, designed for carrying live fishes long distances, has lately been completed and is receiving its special equipment preparatory to being placed in commission. The car is entirely of steel and is thoroughly insulated by the latest improved method to insure against heat and cold. It has a length of 60 feet ½ inch over ends of body plates, and a standard width of 10 feet. The weight of the car with equipment is 150,000 pounds, and is designed to carry a load of 35,000 pounds. In the centre, running lengthwise on each side, are insulated tanks with a total capacity for 130 ten-gallon cans in which fish are held. During transportation the fish will be fur-

nished with oxygen and fresh water by means of air- and water-pumps, operated by a 6-horse-power steam boiler. The boiler will also furnish heat to the car, but, in addition to this independent heating system, the usual train attachment for heating from the locomotive is provided. Tanks for carrying a reserve water supply are located beneath the car, and an ice-box having a capacity of one ton is provided. In addition to the facilities for the transportation of fish, the car is fitted with living accommodations for a crew of five men, a cook's galley, an office, and a space for a dining table.

Fish are distributed by the Bureau of Fisheries in every State of the Union, some 10,000 individual applications being filled annually in addition to the large public plants of the so-called commercial species in the Great Lakes and coastal streams of the seaboards. This phase of the bureau's work has grown to enormous proportions, and in the fiscal year ended June 30, 1915, 49 species were propagated, these including, in addition to fishes, the lobster and several species of fresh-water mussels. The total output of these was over four and a half billions, which were planted in every State and in Alaska. Some idea of the magnitude of the work of distributing fish is indicated by the fact that it involved 637,716 miles of travel, of which 146,544 was by the bureau's special cars and the remainder by car messengers.

The Flow of Viscous Liquids through Pipes. W. K. LEWIS. (*The Journal of Industrial and Engineering Chemistry*, vol. 8, No. 7, July, 1916.)—The carrying capacity of pipes for water under various pressure-drops has been experimentally studied by many engineers, and, while the results are not very concordant on account of the extreme sensitiveness to varying conditions, none the less our knowledge of the resistance to flow of water through pipe lines is relatively satisfactory and complete. On the other hand, practically no work has been published on the resistance to flow through pipes of liquids other than water, despite the fact that information of this sort is of vital importance to the chemical engineer.

It has long been known that, for the flow of liquids through capillary tubes up to 4 or 5 mm. in diameter, according to the formula of Poiseuille, the pressure-drop varies as the viscosity, length, mean velocity, and inversely as the radius squared. Though quantitative data have not been published for the flow of liquids other than water through large tubes or pipes, the paths along which the particles of liquid travel have been studied qualitatively by introducing air or dyes into the fluids and photographing the effects produced by forcing them through glass containers of various shapes and sizes. These observations show that at low velocities liquids move in straight lines parallel to the axis of the tube, but, when the velocity is sufficiently increased, the lines of flow become distorted, the filament forming violent eddies of constantly changing form and position. At the walls of the container there is always a film of

liquid which is retarded by the friction of the solid surface so that it continues to move in straight lines. The mean velocity of the fluid at the point where the change in type of motion takes place is commonly known as the critical velocity, and all flow below this point is called parallel, direct, or viscous motion, while that above is known as turbulent, indirect, or sinuous flow.

Liquids of even moderate viscosity flowing under low heads follow viscous motion, unless the pipes be very large. It is very important to keep in mind the fact that, so long as the motion is viscous, doubling the size of the pipe increases the velocity four-fold and the discharge sixteen-fold for the same pressure-drop. Decrease in size will ultimately result in converting the flow into sinuous motion, after which the effect of size is greatly lessened, being inversely proportioned only to the first power of the diameter.

Railway Motor Field Control. D. C. HERSHBERGER. (*Electric Railway Journal*, vol. xlvii, No. 26, June 24, 1916.)—The prime object of field control is to permit more efficient operation, and, although a field-control equipment is somewhat more expensive in first cost than one without field control, it may be an unwise policy to purchase a non-field control equipment. It has been found in many cases that field-control equipments pay for the additional first cost in two to three years; after this the saving is so much net gain.

Field control has in recent years been applied to all classes of railway service, and the indications are that it will be applied to far greater extent in the future. To date the application of field-control motors in the country amounts to approximately 840,000 horsepower, distributed among some fifty operating companies. It is difficult to determine the total annual saving effected by the use of the field-control motor; it is, however, estimated at approximately one-third of a million dollars per year.

The Corona Voltmeter. J. B. WHITEHEAD and M. W. PULLEN. (*Proceedings of the American Institute of Electrical Engineers*, June 27–30, 1916.)—During a number of years' intermittent experiment on the phenomena attending the electric breakdown of air, one of the most striking observations has been the extreme sharpness, in an ascending range of voltage values, with which this breakdown occurs in the form of corona on clean, round wires. It has been shown beyond question that the appearance of corona depends on the maximum value of the alternating-current wave. Under suitable conditions of observation critical voltage readings repeat themselves with an accuracy equal to that within which the usual direct reading instrument can be read, *i.e.*, of the order of one-tenth of one per cent. Three methods for detecting the first appearance of corona have been developed, in addition to the method of usual observation. These methods involve the use of the electroscope, the galvanometer, and the telephone respectively.

For a given wire, in fixed relation to the opposite side of the circuit, corona-forming voltage depends on the density of the air; that is, on the pressure and temperature. The corona voltmeter consists of a grounded metal cylinder with a central conductor on which corona is formed. Both cylinder and conductor are enclosed in a larger air-tight cylinder, in which the pressure can be varied by a hand-pump. This variation in pressure provides the means by which a wide range of voltage reading is possible. The calibration of the instrument is absolute; that is, it can be calculated or obtained by comparison with existing standards.

The voltmeter is set for a given voltage by adjusting the pressure to a value calculated from the dimensions of the instrument, taken from a calibration table or curve. When the ascending voltage reaches the value for which the voltmeter is set, corona begins, and this is sharply indicated by any one of the three methods mentioned. To measure an unknown voltage, the pressure is gradually lowered from some higher value and is read at the instant corona appears. A calibration curve then gives the unknown voltage.

Kerosene Automobile Engines. C. E. LUCKE. (*Bulletin of the Society of Automobile Engineers*, vol. x, No. 3, June, 1916.)—Use of kerosene in standard gasoline equipment does not produce what can be regarded as satisfactory results from the operating stand-point, because, even in addition to the requirement of gasoline for starting purposes, the kerosene is so little vaporized as to involve troubles of the following well-known order: (*a*) Bad header distribution between carburetor and the several intakes resulting in unequal charges to the several cylinders; (*b*) excessive washing down of lubricating oil from the cylinder walls, due to its solubility in kerosene—proved by the accumulation of kerosene in the crank-case oil; (*c*) smoke and smell in the exhaust or internal carbon, due to decomposition of heavy, unvaporized kerosene drops and wall films, or late vaporizing oil unmixed with air, by the explosion heat of the unmixed part; (*d*) misfires and backfires, due to variations in the mixture as a result of varying degrees of vaporization of the oil that passes the carburetor as the engine temperature varies—especially noticeable with change of throttle, engine speed, or load.

The trouble encountered can be generalized as due to excessively wet mixtures or, inversely stated, to incomplete vaporization, and even to mixtures of a variable degree of vaporization. No particular knowledge of the properties of vapors or of vapor-air mixtures is required to realize that the sort of corrective needed is heat, but it makes all the difference in the world just how the heat is applied. The scientific knowledge of the properties of hydrocarbon liquids and vapors and their vapor-laden mixtures, and the laws of heat transmission through metal walls to get warm mixtures, is no more than sufficient than to indicate just where, how, and to what degree the heat application is to be made.

The problem of adaptation of the gasoline automobile engine to the use of heavier fuels than will vaporize satisfactorily with air without the use of heat is entirely a problem of heating and heaters. Given suitable data on the amount of heat required, on the temperature that should be maintained, on the design of suitable heaters, in shape arrangement and size, on the source or available supplies of heat, on means of establishing and maintaining as long as necessary a suitable starting heat, on the connection between the heated mixture-making apparatus and the engine, and, finally, on the modifications required in the engine so that it will operate properly on the mixtures hot enough to burn without oil or residue, carbon deposits, or smoke—given such data, the kerosene automobile engine can be designed by any engineer. Of course, all this is not available at the present time, but enough is available to put quite satisfactory results within reach now with the ordinary expectation of improvement, perfection, and standardization of such equipment each year of successive use.

"Stainless" Steel. ANON. (*La Chronique Industrielle*, vol. 39, No. 256, June 11, 1916.)—A new alloy of steel, styled "Stainless," containing the notable proportion of 12 per cent. of chromium, has lately come into use in England. It is used with success for cutlery, but its principal advantage is its great resistance to corrosion. According to recent analyses, its typical composition is: Carbon, 0.28 per cent.; silicon, 0.01 per cent.; manganese, 0.12 per cent.; chromium, 12.7 per cent.; cobalt, 0.45 per cent.; iron, 86.6 per cent. In contact with foodstuffs and acids, this steel resists all rusting and tarnishing. Some interesting experiments are now being carried on in England with a view to its application in harbor structures, where the corrosion of structural steel is a serious menace.

Switching Cars by Magnetic Coupling. ANON. (*Scientific American*, vol. cxv, No. 1, July 1, 1916.)—The value of the lifting magnet as a substitute for the crane, hood and shackles is amply demonstrated by its extensive adoption in shops and yards where materials of iron have to be economically handled. Some idea of the holding power of these magnets may be obtained by endeavoring to release from its hold such a small article as a 16-ounce hammer. When fully energized all ordinary effort to a person of average strength is insufficient to separate the hammer from the pole-piece.

At Berne, Switzerland, the authorities have developed this method of connection in the form of magnetic couplers for train-yard switching service. The locomotive is of the storage-battery type, capable of doing a day's work without recharging. At the two ends of the locomotive, and directly opposite where the buffers project from a neighboring car, the tractor has two magnetic buffers controlled by the driver, like the lifting magnet of a crane, and coupling or uncoupling is merely a matter of turning a switch. It takes 440

watts to energize the magnets in service, and the tractive force that can be resisted is 7480 pounds. The pole-pieces are shaped to conform to the buffers to secure good contact, but even with a gap of two-tenths of an inch each magnet is effective for a tractive force of 1980 pounds.

The Synthetic Ruby. ANON. (*La Chronique Industrielle*, vol. 39, No. 256, June 11, 1916.)—For many years chemists and engineers have sought to produce by artificial means and in generous quantity that which Nature had parsimoniously doled out in the course of long ages. Analysis of various gems demonstrated that they were nothing else than alum, crystallized under special conditions. In keeping with the metallic salt present while the gem was in fusion, there resulted the different varieties of stones known under the name sapphire, ruby, topaz, amethyst, or emerald. The one great difficulty to the progress of early investigators lay in the production of the high temperatures necessary for a solution of the problem, and the introduction of the oxyhydrogen torch marked the beginning of the artificial gem industry.

The practical production of artificial gems is due to Verneuil. The basic material is ammonia alum, which is heated in muffles to convert it into calcined alum. To this is added the coloring matter in given proportions: oxide of chromium for rubies, titanic acid for the sapphire. This finely divided powder is allowed to trickle through into the oxyhydrogen flame, which attains a temperature of 1800°. The powder fuses, resulting in the formation of an inverted, pear-shaped body weighing from 10 to 200 carats (1 carat = 0.2 gramme).

Prior to the discovery of the synthetic method now in use, the manufacture of the so-called reconstructed ruby was exploited. These gems are formed by the fusion of a number of small rubies of uniform tint into a larger mass. Many large rubies of the present day have been obtained by this process. It is difficult to fix the date of the origin of the process, those who first conceived it having jealously guarded the secret. At the present time it is entirely abandoned in favor of the synthetic method. These stones have an important industrial value as a bearing material in the running gear of various instruments, and the cheapening of their production is of material advantage in the manufacture of such mechanisms.

Alcohol-benzol Mixture as Fuel for Automobiles. J. E. JONES. (*U. S. Commerce Reports*, No. 164, July 14, 1916.)—According to an article appearing in *Le Progres*, a daily newspaper published at Lyon, among the many efforts made by Germany to counteract the effects of a blockade, one of especial interest is the replacing of gasoline for automobiles by a mixture of alcohol and benzol. With the cessation of imports of gasoline into Germany, the supplies of petroleum drawn from wells in Galicia proved inadequate for the

needs of the Central States. For this reason the German Government instructed the technical department of the transportation service to seek a combustible that would effectively replace gasoline. The outcome of these experiments was the employment of a mixture of alcohol and benzol.

A Mercedes car of the 1914 touring model, having an ordinary carburetor, was used for experimenting purposes. The best result was obtained with a mixture of one part of benzol to one of alcohol, the duty in miles per pint of the fuel being 4.66. Increasing the proportion of alcohol to five parts, the duty continuously lowered to 3.72. With benzol alone, the duty was 3.79; with gasoline, 3.60. At normal prices the use of such a mixture is an economy. One pint of gasoline costs 8.55 cents; benzol, 8.17 cents, and alcohol, 7.79 cents. The difficulty of starting with the alcohol-benzol mixture was overcome by using a supplementary gasoline, benzine, or ether supply until the engine warmed up.

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